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# THESIS

**AN ANALYSIS OF COMMON MISSILE AND TOW 2B USING THE JANUS COMBAT SIMULATION**

by

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June 2002

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The US Army is currently developing a new close combat missile system, Common Missile, to replace the aging Tube-launched, Optically-tracked, Wire-guided (TOW 2B) and HELLFIRE missile systems. The Common Missile will have a greater range and improved target acquisition capability over the current missile systems. The purpose of this thesis is to compare the performance of the Common Missile and the TOW 2B missile in a simulated ground battle situation in three varying terrain conditions. This thesis used the Janus high resolution combat model to simulate the missile systems in a Desert, European and Mediterranean environment. Each of the scenarios used a force-on-force battle to measure effectiveness. Data were gathered from the Janus created postprocessor files of the three scenarios. The analysis compared three measures of effectiveness (MOEs) in the areas of lethality, survivability and engagement range. The goal of the analysis was to determine performance differences between the missile systems by comparing the mean of the simulation results.

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# AN ANALYSIS OF COMMON MISSILE AND TOW 2B USING THE JANUS COMBAT SIMULATION

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# ABSTRACT

The US Army is currently developing a new close combat missile system, Common Missile, to replace the aging Tube-launched, Optically-tracked, Wire-guided (TOW 2B) and HELLFIRE missile systems. The Common Missile will have a greater range and improved target acquisition capability over the current missile systems. The purpose of this thesis is to compare the performance of the Common Missile and the TOW 2B missile in a simulated ground battle situation in three varying terrain conditions. This thesis used the Janus high resolution combat model to simulate the missile systems in a Desert, European and Mediterranean environment. Each of the scenarios used a force-on-force battle to measure effectiveness. Data were gathered from the Janus created postprocessor files of the three scenarios. The analysis compared three measures of effectiveness (MOEs) in the areas of lethality, survivability and engagement range. The goal of the analysis was to determine performance differences between the missile systems by comparing the mean of the simulation results.

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# I. INTRODUCTION

The United States (US) Army has several missile systems that were developed in the 1960-1970s, using then state-of-the-art technology. These missile systems have undergone several iterations of product improvements, to insert emerging technology and improve capability. They have achieved precision kill capability; however, shelf life concerns, increased operational requirements, and budget reductions warrant the replacement of these legacy systems with a new missile system.

Modeling and simulation can be used as a tool early in the acquisition process to predict the capabilities of proposed new missile systems. These predicted capabilities can be compared to the existing systems capabilities to quantify the effect of this investment. This will allow the acquisition process to develop systems that truly increase operational effectiveness and focus on key performance parameters during development.

The Common Missile (CM) system is proposed to replace two of the Army's major missile systems: the Tube-launched, Optically-tracked, Wire-guided (TOW) missile and the HELLFIRE missile. Both the TOW and HELLFIRE missiles are close combat anti-armor guided missile systems. The TOW is primarily ground launched and the HELLFIRE is an air-to-ground missile. CM will be capable of being launched from any of the platforms that the TOW and HELLFIRE missiles currently utilize. CM is presently in early development with a projected fielding in 2008.

This thesis uses modeling and simulation to estimate the performance of both the CM and the TOW 2B (the most recent version of the TOW missile) missile systems in similar engagement scenarios to provide a side-by-side comparison of current and proposed future missile systems capabilities. While this thesis is limited to researching a

few representative ground battle situations, the methodology can be expanded and applied to many more situations and scenarios for a total system assessment.

## A. MODELING AND SIMULATION IN ACQUISITION

The use of modeling and simulation has become standard practice in the acquisition of Army missile systems. Both contractors and the Government agencies rely heavily on modeling and simulation to predict and assess the capability of a missile, both in development and fielding. This has provided huge savings in the reduction of system level flight-testing along with increased ability to evaluate the performance of the missile in untestable conditions. Failures and limitations can be found prior to expensive flight-testing. Accredited models and simulations can assess scenarios and conditions beyond the capability of test ranges. With modeling and simulation, the Army is able to have a greater confidence in their weapon systems at a reduced cost.

The Training and Doctrine Command (TRADOC) Analysis Center (TRAC) has developed several models that simulate the operational aspects of a battle using missiles. These models include a realistic operational environment and allow the users to replicate a battle while accommodating several types of missiles and weapon systems, on multiple terrain types, to simulate an entire battlefield. They allow the addition of new missile and system types. Therefore, they can be used very early in program development, such as in the Concept and Technology Development phase, to estimate the performance of a proposed missile system.

This study will use an existing ground combat simulation program originally developed by Lawrence Livermore National Laboratories (LLNL), Janus, to perform a comparative analysis between the new CM and the existing TOW 2B. Estimated performance parameters of CM were obtained from the Program Executive Office (PEO)

Tactical Missiles and Project Offices within this PEO. The TOW 2B missile system is already modeled in the Janus simulation.

## B. OBJECTIVES AND PURPOSE OF THE RESEARCH

Early assessment of potential capabilities of a new missile system can set the stage for success when the system is eventually fielded. Being able to quantify how well a missile system performs in a specific scenario adds much value from both a communication and technical standpoint. With this information, it is easier to describe the benefits of the proposed missile system. This information also allows the developer to focus on performance parameters that have the most positive impact. This research used modeling and simulation to estimate the performance of the proposed CM system and the existing TOW 2B missile system. Three different terrain locations were used with an applicable battle scenario created for each location. Both systems were evaluated at each terrain/scenario combination for a side-by-side comparative analysis. This showed the differences in performance between the systems under several different environmental conditions. Additionally, it demonstrated which cases provide the biggest and least difference in performance between the two missile systems.

## C. RESEARCH QUESTIONS

The primary research question is:

To what extent do simulation results indicate that CM will be more effective than TOW2B?

Subsidiary research questions are:

1. To what extent does geographic location affect the projected performance difference between CM and TOW 2B?

2. What are possible reasons for variations in performance from one geographic location to another?

3. Can the techniques described in this study be reasonably expanded and applied to additional scenarios and terrains?

## D. SCOPE, LIMITATIONS AND ASSUMPTIONS

This thesis consists of an analysis of the operational effectiveness of the CM and the TOW 2B missile system. The Measures of Operational Effectiveness (MOEs) were defined as the number of losses on both sides (blue and red) and average range of engagement. Performance parameters of both missile systems were identified and entered into the Janus combat simulation. These parameters are limited to an unclassified version of the systems. A realistic close combat ground scenario was defined. Janus simulated a battle using each missile system in the scenario defined. This scenario was then applied to two additional terrain locations. Additional scenarios or battle formations were not included in this study. Other factors that potentially affect missile system performance, such as weather also were not addressed in this thesis. This research was limited to the capability of the Janus simulation. No modifications were made to the Janus program.

## E. METHODOLOGY

The methodology of research for this thesis follows seven basic steps: literature and background search, Janus review and understanding, missile system creation in

Janus, scenario and terrain set up, run simulation, analysis of results, documentation of results, and conclusions. Each step is described in more detail in the following paragraphs.

The literature and background search began with reviewing other simulation studies that have been done on similar weapon systems. This included any simulation, but focused on those studies using Janus. Information was also collected describing both the CM and TOW 2B missile systems. This information primarily came from the PEO Tactical Missiles and project offices within this PEO. Additionally, Army Field Manuals were reviewed to assist in determining a realistic force structure for both friendly and Opposition Forces (OPFOR). Finally, statistical references were researched to determine the best statistical method to analyze the simulation data.

The Janus review and understanding step was performed at TRAC – Monterey, located on the Naval Postgraduate School (NPS) campus. The documentation and tutorial were reviewed to gain an understanding of the Janus model and simulation, how it works, and its capability and limitations. At this point the parameters defining the missile systems, their platforms and the target systems were defined and entered into the Janus simulation as a new system. The parameters were provided or reviewed by the PEO Tactical Missiles for accuracy prior to executing the simulation runs.

The next step consisted of designing the scenario. Before any simulation runs were conducted, a plan defining the scenario, terrain, and run matrix was created. The scenario defined the friendly (Blue) and enemy (Red) systems by type and quantity as well as their battle plan and movements. This scenario was overlaid on a terrain map on which the battle was fought. Two additional battle locations were chosen and appropriate similar scenarios were created on these terrains. A run matrix defining the conditions of each simulation iteration or run was also created. Additionally, assumptions and limitations such as "end of battle" criteria were defined and documented.

After the simulation plan was finished, the simulation runs designated in the run matrix were executed. Data from each run were collected and documented for simple statistical analysis such as calculating the mean, standard deviation and range of the simulation results.

The final step was documenting the results of the analysis and determining any conclusions and recommendations that can be made from the research.

**F. ORGANIZATION OF STUDY**

This thesis consists of seven chapters. The first chapter is an introduction and provides the structure and lays the groundwork for the research methodology. Chapter II describes both the CM system and the TOW 2B missile system to provide the reader with knowledge of the general characteristics of these two missile systems.

Chapter III provides a description of the scenarios to include the friendly and opposing force structure and the terrain type and locations where the scenarios are applied. The measures of effectiveness (MOEs) that define specific performance of each missile system are also defined.

Chapter IV describes the Janus combat simulation and how the missile systems and scenarios are created within this simulation. The number and type of simulation runs and output format are also discussed.

Chapter V and VI present the data and analysis respectively. The data are presented graphically and simple statistical methods are used to assess the differences in performance between the CM and the TOW 2B missile.

The final chapter includes conclusions and recommendations, and provides answers to the primary and subsidiary research questions.  Additionally, the final chapter suggests areas that require further research.

## G.  BENEFITS OF THIS RESEARCH

This study provides the PEO Tactical Missiles additional information on the projected performance of CM in comparison to the existing TOW 2B missile system. Additionally, it identifies geographic locations where the difference in performance capability is more and less pronounced. This will allow the PEO and the Army to support the need and quantify the benefit of procuring and fielding a new missile system.

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# II. COMMON MISSILE AND TOW 2B

## A. BACKGROUND

The TOW missile is a crew portable, vehicle-mounted, heavy anti-armor weapon system consisting of a launcher and one of five versions of the TOW missile. It is designed to defeat armored vehicles and other targets, such as field fortifications, for ranges of 500 to 3,750 meters. After firing the missile, the gunner must keep the crosshairs of the sight centered on the target to ensure a hit. The missile is steered along a line-of-sight path via a pair of wires, which physically link the missile and the launcher. The system will operate in all weather conditions that allow the gunner to see a target throughout the missile flight with the use of either a day or night sight. The TOW system is used on the High Mobility Multipurpose Wheeled Vehicle (HMMWV), the M151 jeep, the Armored Personnel Carrier (APC), the Bradley Fighting Vehicle (BFV), Cobra helicopters, the Improved TOW Vehicle (ITV), and the United States Marine Corps (USMC) Light Armored Vehicle (LAV) [Ref. 1]. The TOW missile system was originally fielded in 1970 and was the first American-made guided missile to be fired by United States (US) soldiers in combat in Vietnam in 1972 [Ref. 2]. The most recent variant, TOW 2B, ended production in 1997 [Ref. 1]. This thesis will focus on the TOW 2B version, since it is the most recent. The TOW stockpile is beginning to exceed its shelf life and operational inventory will drop below the requirements for TOW missiles in 2005.

Figure 1. The TOW Missile Fired from a Jeep

HELLFIRE is an air-to-ground missile system designed to defeat tanks and other individual targets while minimizing the exposure of the launch vehicle to enemy fire. HELLFIRE uses laser guidance. The missile homes in on a laser spot that can be projected by ground observers, the launching aircraft, or other aircraft. It is used on helicopters against heavily armored vehicles at ranges up to 8 kilometers. Current launch platforms include the AH-64 APACHE and the Marine Corps AH-1W Super Cobra helicopters. The Hellfire missile can also be launched from the MH-60 Black Hawk and OH-58D Kiowa Warrior helicopters [Ref. 2]. The HELLFIRE missile system was originally fielded in 1982 and was first fired in combat during Operation Just Cause in Panama in 1989 [Ref. 2]. Hellfire II missiles will begin falling below stockpile requirements in 2008.

Both TOW and Hellfire missile systems are managed by the Program Executive Office (PEO) Tactical Missiles. The PEO has recognized an opportunity to meet future battlefield needs at reduced costs. Instead of developing unique missile systems to satisfy the requirements for each specific platform, current technology can support the development of a single missile system that may be employed on a variety of platforms that meet both ground and air requirements. The CM concept emerged from this idea. Benefits from commonality range from technical; a common launcher interface and significant commonality in fire control algorithms, to operational; cross-leveling missiles between air and ground platforms, to logistics; reductions in aggregate missile totals

required in theater, common training and test procedures and common storage. Additionally, the development and production programs for a common missile will yield a reduction in life cycle cost over two separate and distinct systems developed to separate air and ground requirements.

## B. COMMON MISSILE SYSTEM DESCRIPTION

The CM system is in the Concept and Technology Development phase of acquisition and is managed by a recently formed Army Project Office at Redstone Arsenal in Huntsville, AL. CM is also called Joint CM and will be developed jointly by the Army and Marine Corps. There are also plans for a Memorandum of Agreement (MOA) with the United Kingdom (UK) in which the UK will provide some funding in return for the right to buy CM at US prices [Ref. 3]. The proposed missile is an all weather precision strike guided missile system for ground, rotary wing and fixed wing applications with a range of approximately 12 kilometers [Ref. 1].

The CM system concept leverages current missile technology. Figure 2 depicts the major subsystems of CM. It is a chemical energy missile with an Electronic Safe and Arm Device (ESAD) and a conventional warhead. Propulsion will be provided by a solid rocket motor. Guidance and control will be achieved with an on board Inertial Measurement Unit (IMU) and a Control Actuation System (CAS), which controls the fins. An on board computer will process seeker information and coordinate the actions of all the subsystems.

CM will contain a state of the art multi-mode seeker. The three seeker modes will be Imaging Infrared ($I^2R$), Laser Spot (SAL), and MilliMeter Wave (MMW). This will allow the missile to operate in several modes and provide several engagement options. It can operate in the traditional Man-In-The-Loop (MITL) mode with the gunner/aviator/observer illuminating the target (SAL mode) and the missile locking on

either before or after launch depending upon the line-of-sight condition. With the additional $I^2R$ and MMW seekers, the missile can also operate in a fire-and-forget mode allowing the firing vehicle to relocate immediately after launching the missile.

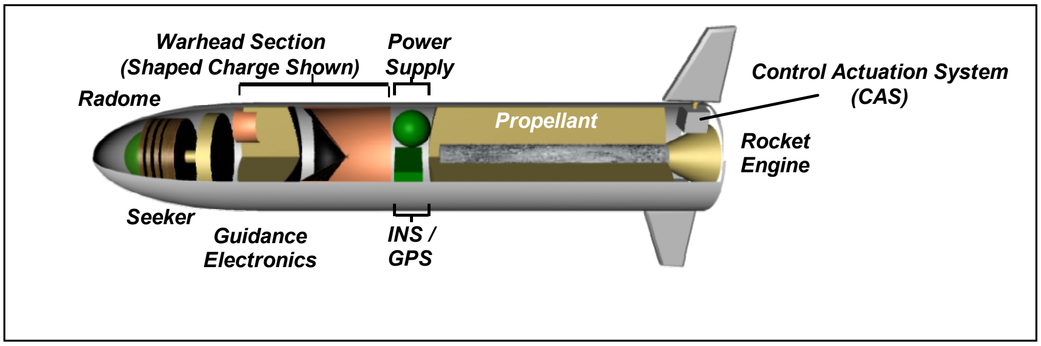


Figure 2. Common Missile Conceptual Drawing

The primary target sets for CM are combat vehicles such as tanks, Armored Personnel Carriers (APC), and air defense systems. Secondary targets include helicopters, buildings, bunkers, and Command, Control, Communications and Information (C3I) units.

CM is designated as a primary system on Comanche and a candidate for Future Combat System (FCS). It will also be backward compatible with existing TOW and HELLFIRE launch platforms.

CM is in a technology development process with many concept development contracts. Currently there are four contracts for the system definition, and several more contracts for each of the major subsystems (propulsion, seeker and warhead). This contract activity has the primary purpose of defining the system and subsystems and early risk reduction leading into the next program acquisition phase. The System Development and Demonstration (SDD) phase is scheduled to begin in 2004.

## C. TOW 2B MISSILE SYSTEM DESCRIPTION

The TOW missile system is in the Operations and Support phase of acquisition and is managed by the Close Combat Anti-Armor Weapon Systems (CCAWS) Project Office at Redstone Arsenal in Huntsville, AL. There are five versions of the TOW missile: Basic TOW, Improved TOW, TOW 2, TOW 2A and TOW 2B. The TOW is no longer being produced for US forces.

The TOW missile is capable of penetrating more than 30 inches of armor, can be fired by infantrymen using a tripod as well as from vehicles and helicopters and can launch three missiles in 90 seconds [Ref. 2]. Primary targets are tanks. Secondary missions are point targets such as non-armored vehicles, crew-served weapons and launchers.

The system is composed of a reusable launcher, a missile guidance set, and a sight system. The Improved Target Acquisition System (ITAS) is the most recent target acquisition system for HMMWV launched TOW missiles. ITAS uses a second generation forward looking infrared (FLIR) system, digital components and an eye safe laser range finder. The detection range of the ITAS is beyond the maximum range of the TOW missile.

TOW 2B is the most recent version of the TOW family and increased the lethality, over the previous variants, by incorporating a fly-over, shoot-down flight path to the target. TOW 2B flies over the target and uses a laser profilometer and magnetic sensor to detect and fire two downward directed, explosively formed penetrator warheads into the target. Other major components are a launch motor, flight motor, and guidance beacon assemblies. Figure 3 provides a breakout of the major components of the TOW 2B missile.

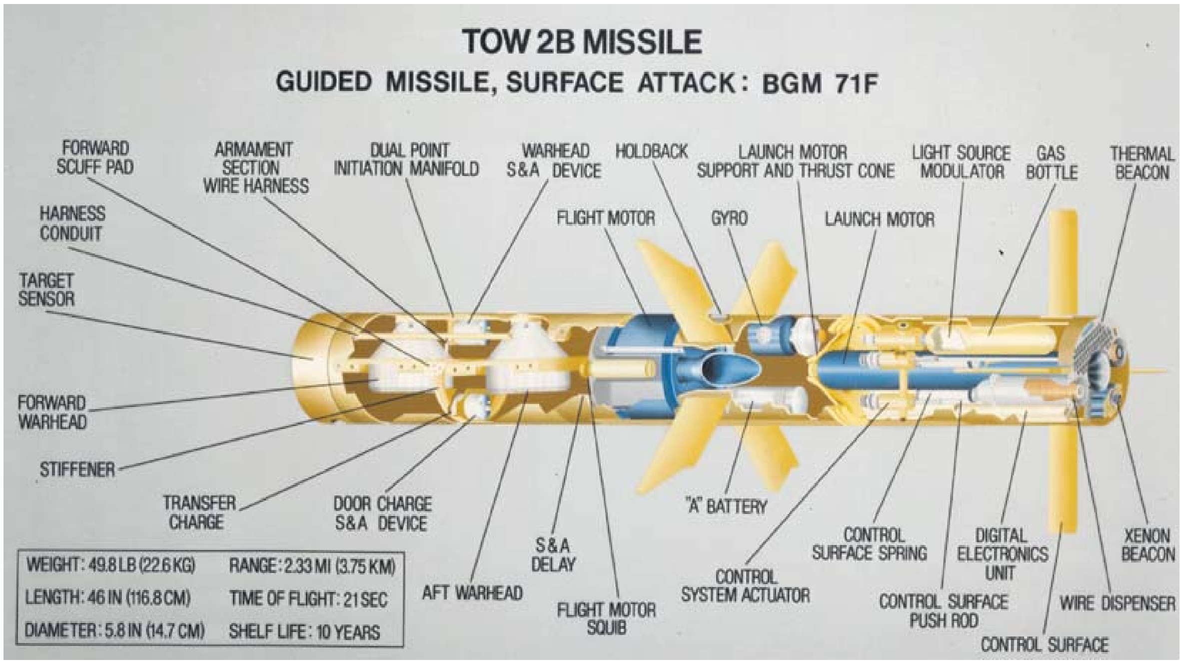


Figure 3. The TOW 2B Missile and Major Components

The TOW is the most widely distributed anti-tank guided missile in the world with over 500,000 built and in service in the US and over 40 allied countries [Ref. 2]. TOW missiles are no longer being produced for US forces, however the TOW 2A and TOW 2B are still being produced for Foreign Military Sales (FMS).

The TOW and the proposed CM missiles are similar in many respects with the same launch platforms and target sets. CM however, should provide a significant increased operational capability with its increased range, accuracy and fire-and-forget features.

# III. SCENARIO DESCRIPTION

The purpose of this chapter is to describe the close combat ground battle scenarios used to evaluate the performance of both the CM and TOW 2B missile systems. These scenarios were developed with guidance from the PEO Tactical Missiles. Two main considerations during scenario creation were: portraying a realistic scenario and defining a scenario that would expose performance differences between the two missile systems being evaluated.

Three vignettes were chosen to represent different terrain conditions. Each vignette description includes the terrain location chosen, from the TRAC-Monterey database, and the force structure. The force structure will be defined by the type and quantity of elements representing both the friendly (Blue) and opposing (Red) sides and their movement patterns. The final section in this chapter defines the measures of effectiveness (MOEs) that were identified for the comparison of the CM and the TOW 2B missile under the three vignettes.

## A. FORCE STRUCTURE

### 1. Friendly Force

The Blue force consisted of three platoons of HMMWVs. Each HMMWV platoon consisted of two sections of two vehicles, four vehicles total. The HMMWVs were equipped with the ITAS target acquisition system and either seven TOW 2B missiles or seven CMs. In all vignettes the platoon was in a deliberate partial defilade defensive position, sited to provide good fields-of-view and fields of fire in which to employ either the TOW 2B or CM system at the maximum range possible for the given terrain.

In all vignettes, the HMMWV platoons were in a delaying position, used to slow the Red force advance, to allow time for preparation of the main defense position. These platoons would normally employ artillery assets to reduce and disrupt the enemy at maximum range causing delay to the advancing opposing force; however, these artillery assets were not used in the simulated scenarios because the comparison of the two missile systems alone is the desired result of this study.

### 2. Opposing Force

The Red force consisted of two tank companies and an infantry fighting vehicle company. Each tank company consisted of ten T-72 tanks, and the infantry fighting vehicle company consisted of three platoons of three BMP-2 vehicles, a company command vehicle, and an Anti-Tank Guided Missile (ATGM) section of two vehicles, for a total of 32 opposing force vehicles [Ref. 4]. Each T-72 carried an AT-11 ATGM launcher and six laser beam-riding missiles, as its main weapon [Ref. 5]. The AT-11 has an effective range of 4000 meters. The 12 BMP-2 vehicles each carried an AT-5 ATGM launcher and four wire guided missiles [Ref. 5]. The AT-5 has an effective range of 4000 meters. In addition, the BMP-2 carried a 30mm automatic gun with 500 rounds.

The Red vehicles were advancing in all vignettes. The attack formation in each vignette is either column (Figure 4) or wedge (Figure 5) depending upon the terrain conditions. This is described in further detail in the following paragraphs.

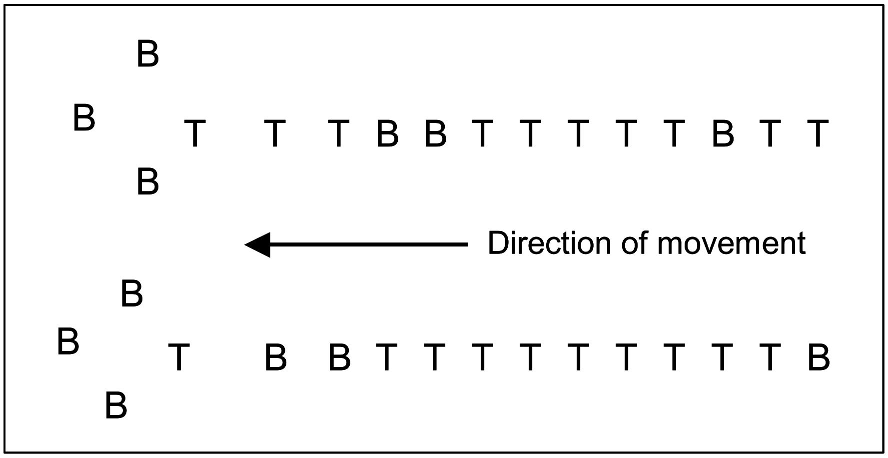


Figure 4. Red Force Column Formation

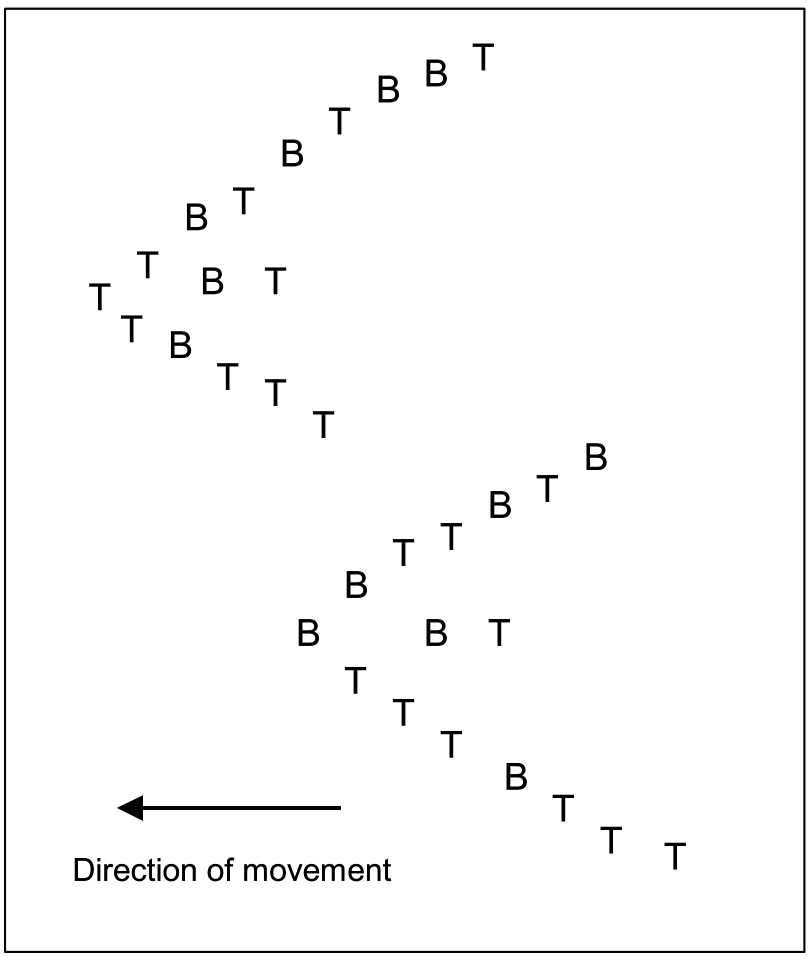


Figure 5. Red Force Wedge Formation

## B. VIGNETTE DESCRIPTIONS

This section describes each of the three vignettes chosen for the simulation experiment. All vignettes have similar opposing force movements and friendly force positions. In all cases, the Red force was advancing toward the friendly position from beyond maximum visibility range. The Red force had the mission of capturing an objective to the rear of the Blue force. The mission of the Blue force was to defend against this attack. The Blue plan was to fight the battle in depth from preplanned defilade positions. Once the first detection and engagement occurred from either side, the opposing force continued advancing, stopping only to fire its weapons, and resuming movement immediately after firing. The simulation of this vignette continued with the Red force attacking the Blue position until either all HMMWVs or all T-72s and BMP-2s were destroyed.

### 1. Vignette 1 – Desert

The first vignette is on terrain located at the National Training Center (NTC) at Fort Irwin, CA. It represented a desert environment with a dry climate, minimal vegetation, and terrain with flat plains bordered by steep mountains. In this vignette the Blue force positioned themselves on a ridge overlooking a valley passageway between two steep mountains. Two HMMWV platoons are overlooking the "valley of death" and the third platoon is positioned at the precipice of the ridge, so that they will be able to attack the Red forces if they choose to take an alternate route to the south of the Blue positions (see Figure 6). The Red force is in a wedge formation of two columns, of equal number of vehicles, each lead by T-72s. The remaining vehicles in each column were following approximately in a V formation behind the leaders. One wedge column was leading the advance with the other following behind and slightly south. Since there few roads and level terrain, the vehicles were traveling cross-country. Once detection and engagement occurred between the first wedge of Red forces and the Blue forces, the

second wedge of Red forces took an alternate route south of the ridge, from where the Blue forces were attacking, thus avoiding the “valley of death”.

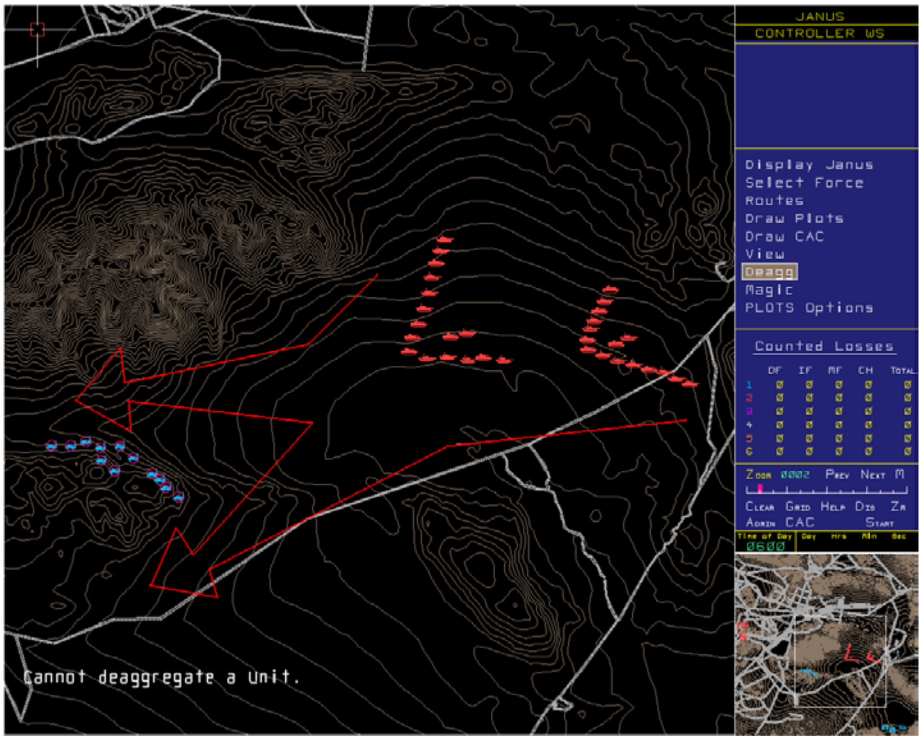


Figure 6. Janus Screen Display of Vignette 1 – Desert

## 2. Vignette 2 – European

The second vignette was on terrain near Sarajevo, Bosnia. It represented a European environment with a seasonal climate, dense vegetation, and rugged terrain. In this vignette the Blue force positioned themselves outside the city in a wooded area overlooking a major roadway entering the city. Two of the HMMWV platoons were defending the major road and one platoon was defending the secondary road (see figure 7). The Red force is in a formation of two columns each lead by T-72s. The remaining vehicles in each column were following directly behind the leaders on the road. One column was on the major road and the second column was on the secondary road. The columns are divided unevenly with the first column having 20 vehicles and the second column having 12 vehicles.

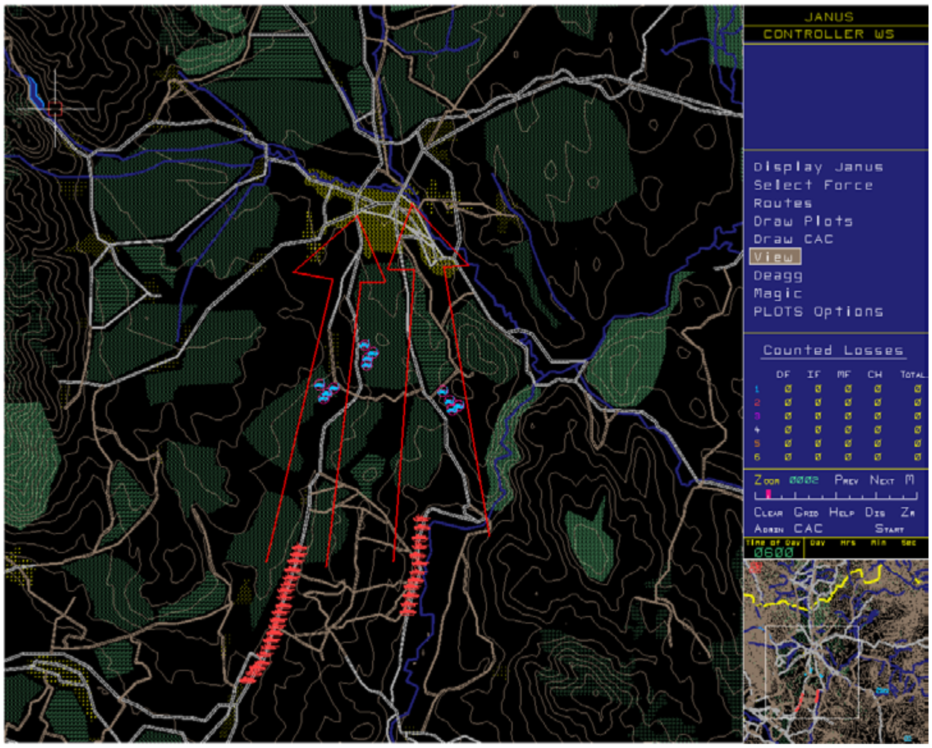


Figure 7. Janus Screen Display of Vignette 2 – European

### 3. Vignette 3 – Mediterranean

The third vignette was on terrain at Fort Hunter Liggett, CA. It represented a Mediterranean environment with a mild climate, moderate vegetation, and terrain with level valleys bordered by gentle hills. In this vignette the Blue force positioned themselves on a ridge overlooking a valley facing the oncoming opposition force (see figure 8). The Red force was in a formation of two columns each lead by T-72s. The remaining vehicles in each column were following approximately in line behind the leaders. Since there are few roads and clear terrain, the vehicles were traveling cross-country.

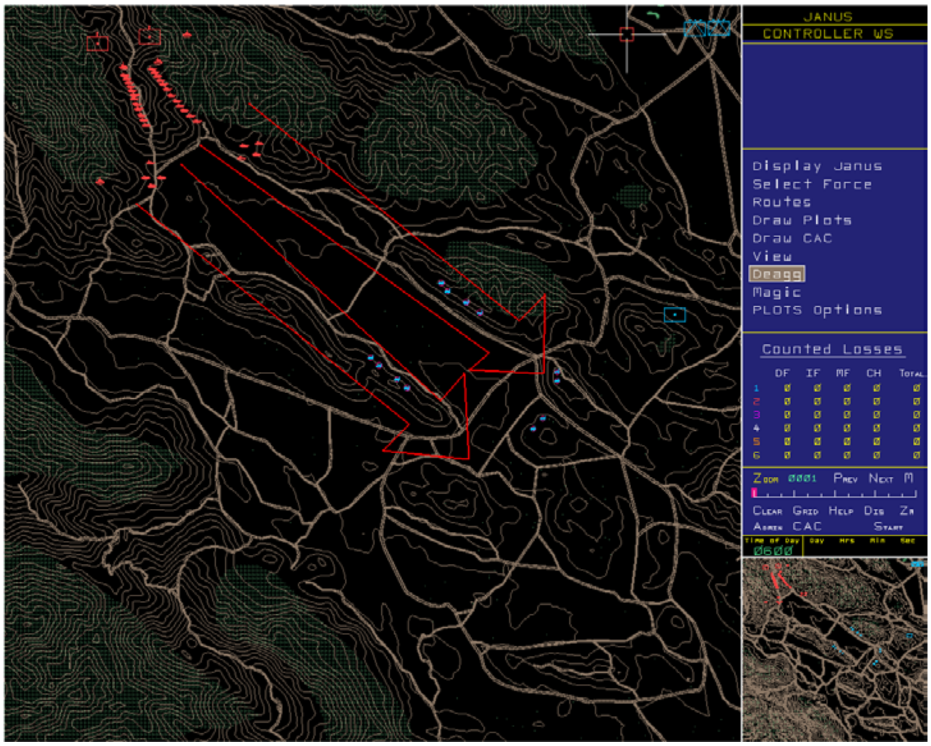


Figure 8. Janus Screen Display of Vignette 3 - Mediterranean

## C. MEASURES OF EFFECTIVENESS

The TOW Test and Evaluation Master Plan (TEMP) [Ref. 6] contains two Critical Operational Issues (COIs) that are used to evaluate field and operational testing. Since the CM is planned as a replacement of the TOW missile, the TOW COIs are considered applicable for the CM system. A TEMP has not been created for the CM yet. The two COIs are:

a. Is the TOW missile operationally effective in the close-in battle?
b. Is the TOW missile operationally suitable for sustained operations?

Lethality, survivability and engagement capabilities play a significant part in assessing the missile system's ability to satisfy the first COI. Modeling and simulation can provide an indication of how well the missile systems address this COI. This COI forms the basis of the Measures of Effectiveness (MOEs) selected for use in this thesis.

A MOE is defined as a parameter that evaluates the capability of the system to accomplish its assigned missions under a given set of conditions. The MOEs chosen for this study were lethality, survivability and engagement range. These MOEs are described in further detail in the following paragraphs.

### 1. MOE 1 - Lethality

The first issue considered was lethality of each missile system. Lethality is defined as the number of vehicle kills the platoon is able to inflict on an attacking enemy. Specifically, MOE 1 equals the number of enemy (Red) vehicle kills.

### 2. MOE 2 - Survivability

The second issue considered was survivability afforded the HMMWV platoons with the use of each missile system. Survivability is defined as the number of HMMWV vehicles destroyed during battle. Specifically, MOE 2 equals the number of friendly (Blue) vehicle kills.

### 3. MOE 3 - Engagement Range

The third and final measure considered was the range at which the platoon is able to engage the enemy. Longer engagement ranges positively affect the survivability of friendly forces by killing the enemy before they can kill you. Specifically, MOE 3 equals the average engagement range of friendly (Blue) shots that kill enemy (Red) vehicles.

The next chapter describes the elements of the Janus simulation and how the TOW 2B and CM, along with the scenarios described previously in this chapter, were modeled in Janus.

# IV. JANUS COMBAT MODEL

The Janus combat simulation is managed by TRAC – White Sands Missile Range (WSMR). It can be used for both training and analysis of weapon systems. This chapter describes the Janus program, the inputs used to model TOW 2B and CM systems, and the simulation approach.

## A. GENERAL DESCRIPTION

Janus is an interactive, stochastic, combat simulation program "named for the two faced Roman god who was the guardian of portals and the patron of beginnings and endings." [Ref. 7]. Initially Janus was a two-sided ground combat model. Later versions have been developed to include up to six sides and some air and amphibious operations. The system can depict multiple opposing forces that can be "played" against each other. The system allows interaction between the operator and the simulation by allowing the controller to make real-time decisions or changes in the combat operation. This is useful for training applications. The simulation is considered realistic because it is closed, meaning the disposition of opposing forces is not known to the operator until a system under his control detects the enemy system. Finally, stochastic refers to the way in which the results of an engagement are determined. Probabilities are used to determine if there is detection and an ensuing miss or kill of the target.

Janus also allows a complete battle to be preplanned, including deployed positions and movements, for later automatic replay. This aspect of Janus is most useful for analysis of weapon systems and will be discussed in greater detail later in this chapter. Since this thesis focuses on a structured comparison of two missiles systems under the same conditions, the automatic rather than interactive feature of Janus was used. In all cases the simulations were run without any human input during the battle.

In Janus a group of scenarios can be stored in a project file. This is similar to several computer files being stored in a folder. This project file contains all the information necessary to run the simulation. This includes all the information about the terrains, the weapon systems, the force structures and the "battle plan" describing the movements and actions of all the elements on all sides of the battle. The following paragraphs describe the main sections of Janus that tie together to form a project. Once a project is created in Janus, it can be copied and modified for ease in creating similar scenarios. For this thesis the project was named "groundCM" for Ground CM.

## B. TERRAIN

The National Imagery and Mapping Agency (NIMA) and the Naval Postgraduate School (NPS) developed the terrain depicted in Janus. Any terrain that can be digitized can be input into Janus. In addition, the modeler can further modify the terrain at the Janus workstation. The terrain viewed at the workstation looks very similar to a military map. Contour lines differentiate between elevations. Green areas indicate areas of vegetation. Roads, rivers, and urban areas are also depicted on the workstation monitor. Terrain plays a critical role within the simulation because it dictates the line of sight of a specific weapon system.

## C. WEAPON SYSTEM

The Janus program uses a database to store and access information on particular weapon systems. A new weapon system can be added by either entering all the characteristics of that weapon system or modifying the appropriate characteristics of an existing weapon system. The database is divided into sections such as system, weapon, sensor, chemical, engineer, and weather. The sections applicable to this study are the system, weapon and sensor and will be described further in the following paragraph.

System characteristics define the weapon system being modeled. For TOW 2B and CM, the system is the HMMWV vehicle, with the target acquisition system, the

missile launcher, and seven TOW 2B or CM rounds. System information used by Janus includes characteristics such as maximum speed, maximum visibility, and weapon types. Weapon characteristics define the individual weapon, such as missile, rocket or ammunition. Weapon information used by Janus includes characteristics such as aim and reload times, rounds per trigger pull, round velocity and maximum range. Sensor characteristics include Direct View Optics (DVO) and temperature or contrast tables for thermal or optical sensors respectively. These sensors can either apply to the system, i.e. target acquisition system, or to a weapon, i.e. guided missile.

## D. MODELING TOW 2B AND COMMON MISSILE IN JANUS

This section describes specific inputs used to define both the TOW 2B and CM systems. The Janus database at TRAC – Monterey already included a weapon system consisting of a HMMWV vehicle, an ITAS target acquisition system, and seven TOW 2B missiles. This existing weapon system was modified to create a new weapon system to represent the HMMWV launched CM. Modifications to represent CM were made only in the systems and weapons sections of Janus. A representative from PEO Tactical Missiles reviewed the existing TOW 2B system and weapon characteristics and assisted in creating the CM system and weapon in Janus [Ref. 8]. It is important to point out that the parameters used to define the TOW 2B missile system are more precise than those used to define the CM system. Since TOW 2B has been in the field for many years, its design is well known and understood. CM is in very early development. The parameters used to define the CM are based on the best engineering knowledge at this point in time. All data used in this thesis are unclassified which further limits the representation of CM and its sensor. The following paragraphs will briefly describe the system, weapon and sensor sections of the Janus database and changes made from TOW 2B to reflect CM. A complete listing of the inputs used for both TOW 2B and CM is contained in Appendix A.

### 1. Systems Section

As stated previously, the system section of the database contains information that describes the entire weapon system, to include the vehicle, target acquisition system and weapons on board. In the existing Janus database, the system representing a HMMWV with ITAS and TOW 2B missiles was named "System 92". A copy of System 92 was made to form the basis of the CM system. This new system was named "GNDCM", short for ground CM. Within the systems section are the characteristics and weapons and ordnance subsections.

The characteristic subsection establishes the system's basic operational data. This section contains information describing characteristics such as maximum velocity, maximum visibility and weapon range. The only modification made, in this section, to represent CM, was the weapon range, from 3.75 kilometers to 6 kilometers. The full 12 kilometer range capability mentioned in Chapter II was not used in this study because the longer ranges are considered only applicable for air to ground missions rather than close combat ground situations. The maximum visibility applies to the target acquisition system and was increased from 6 kilometers to 7 kilometers to accommodate the increased missile range.

The weapons and ordnance subsection of the system section describes the basic load, which is the number of weapons carried by each of the systems. Since CM is envisioned to be backwards compatible with all TOW platforms, the system load of seven missiles was not changed.

### 2. Weapons Section

The weapons section of the database contains information that describes the individual weapon or round, to include aim and reload times, rounds per trigger pull,

round velocity and maximum range. In the existing Janus database, the system representing a TOW 2B missile was named TOW. A copy of weapon TOW was made to form the basis of the CM. This new weapon was named "CM DF", short for CM Direct Fire. Within the weapon section are the characteristics, round guidance, probability of hit ($P_H$) and probability of kill ($P_K$) subsections.

The characteristics subsection defines the general characteristics of the missile such as lay time (time it takes to stop and be ready to fire), aim time (time it takes to fire weapon once target is detected), reload time, and round speed. Modifications for CM were made to lay time, reload time and round speed. All changes were based on information provided by the PEO. Lay time was decreased from seven to six seconds. Reload time was increased from 38 seconds to 60 seconds. Round speed was increased from .180 to .400 kilometers per second.

The round guidance subsection contains information regarding how the missile is guided to the target. It includes whether the missile has an on board sensor and the type of sensor, such as thermal or optical. It also includes fire on the move information such as whether a system must stop before firing and if so, does the system have to wait until target impact to resume moving. Modifications were made in this subsection to reflect an on board thermal sensor for CM. A change was also made to reflect the capability for system movement prior to target impact or "fire-and-forget" for CM.

Probability of hit is defined as the probability of hitting a target at a given range given a single trigger pull. Probability of kill is defined as the probability of killing a target given a target hit. Both $P_H$ and $P_K$ are functions of range. Janus uses a probability function to describe the $P_H$ and $P_K$ for a given weapon as a function of range. Unclassified $P_H$ and $P_K$ information for CM was provided by the PEO and input in these subsections. See Appendices A and B for specific $P_H$ and $P_K$ information.

### 3. Sensors

The sensors section defines the general characteristics of sensors on both the system and the weapon. The characteristics contained in this section include measurements for narrow and wide field of view and temperature versus cycles per milliradian. Since both the TOW 2B and the CM will use the ITAS target acquisition system, the sensor characteristics for both systems are identical. As mentioned in the previous section, the CM weapon guidance data were changed from the TOW 2B guidance data to reflect the seeker on the CM itself. While Janus does have the capability to model an on board sensor, it does not allow for a tri-mode type seeker such as the one planed for CM. A standard thermal sensor that was already in the Janus database was used to approximate the CM seeker. These sensor characteristics were reviewed by the PEO and they are listed in Appendix A.

## E. FORCE STRUCTURE

The force structure can be created once the system and weapons are properly defined in the Janus database. Janus uses a "force editor" feature as a tool to define the forces on each of up to six sides. For this thesis, only two sides, friendly (Blue) and opposing (Red), were used. In the force editor, the individual elements of the Blue and Red forces, as described in Chapter III, were selected and added to each side. At this point, the scenario was created.

## F. SCENARIOS

In Janus, a scenario basically consists of terrain, a force structure (using systems and weapons from the database), and a movement plan for each force. The Janus simulation provides many functions that allow the user to realistically model combat between two opposing forces. The final step prior to running the simulation is planning the sequence of events for each scenario. After these sequences are captured, they can be

replayed for many iterations or runs. Each run differs only due to the stochastic nature of the simulation process. The following paragraphs briefly describe the Janus functions used to create a force movement plan and the scenario notation used for this study.

### 1. Simulation Planning

Each simulation has two phases, the planning phase and the execution phase. During the planning phase, the vehicle icons are positioned in their start locations. The controller is also able to enter planned movement routes for the vehicles to follow in the execution phase. In all scenarios, the start locations are approximately ten kilometers between forces and beyond the line of sight for either side. The controller also sets each vehicle's field of view (FOV) with respect to the direction it is looking. The vehicles that are moving look throughout a 360-degree FOV. Since the Blue forces are stationary and the Red forces are moving, the FOV selection was only significant for the Blue forces. Pre-determined vehicle routes are entered as straight lines between nodes. The nodes may be "stop", "go" or "timed" nodes. When the simulation is executed, the vehicles will follow the same movement plan for each run. A moving vehicle is in an exposed state. In all scenarios, the Red forces are in constant advancement. Janus also provides a preposition function that allows the controller to create prepared fighting positions for vehicles. Vehicles in preposition will acquire in a full defilade status, change to partial defilade to fire, then return to full defilade. Prepositioning was used to place the Blue forces in a deliberate defensive position.

### 2. Scenarios

In the last chapter the three vignettes, European, Desert, and Mediterranean, were described in some detail. This study required the creation of six scenarios to examine the performance of the two missile systems at three different locations. These scenarios are numbered and defined as follows:

a. Scenario 228 – TOW 2B in Desert vignette

b. Scenario 229 – TOW 2B in European vignette

c. Scenario 230 – TOW 2B in Mediterranean vignette

d. Scenario 238 – CM in Desert vignette

e. Scenario 239 – CM in European vignette

f. Scenario 240 – CM in Mediterranean vignette

Janus screens depicting these scenarios were shown in Chapter III. The figures show the force locations and routes used by the attacking vehicles.

## G. SIMULATION EXECUTION

When the simulation planning phase is complete, the simulation execution phase can begin. The simulation execution phase consisted of determining the number of repetitions or runs necessary to collect sufficient data, performing the runs, and recording the data.

### 1. Number of Runs

Each Janus simulation run requires interaction by the controller and it can be a time consuming process to execute a large number of runs in each of the six scenarios. All six scenarios produce a value for each MOE, which can quickly add up to hundreds of data points. Previous Janus studies suggest about ten runs to provide sufficient variability in outcome that support analysis. However ten sample points is usually not enough for statistical analysis. Therefore, twenty-five runs of each scenario were performed.

### 2. Postprocessing Files

As each simulation run is made, Janus records all the data compiled during the battle. These files include data such as movement routes, detections and direct fire shots. With these files, the controller is able to replay the battle to analyze it more closely, or produce postprocessing files. The postprocessing files provide printed or screen reports containing killer-victim scoreboards (Coroner's Report), detection reports, engagement range data and other information that can be used to conduct the analysis. Data relating to the MOEs defined in Chapter III were extracted from these postprocessing files. An example of a postprocessing file is shown in Appendix C. The next chapter presents and explains the data.

At this point, CM and TOW 2B missile systems are modeled, as accurately as possible, and the battle scenarios are defined within the Janus simulation. A total of 150 simulation runs (25 runs for each of the six scenarios) were performed. The next chapter presents the results of these simulation runs.

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# V. DATA PRESENTATION

The raw data gathered from the postprocessing files are shown in Appendix D. There is one postprocessing file for each run of each scenario. Data for MOEs 1 and 2 were taken from the Coroner's Report portion of the postprocessing files. The Coroner's Report lists each kill, showing the victim and the killer by vehicle type, in chronological game time order. For MOE 1, the separate lists of BMP-2 and T-72 kills were combined to form the total number of Red kills. Data for MOE 2 were extracted directly from the Coroner's Report without any modification since there is only one type of Blue target, the HMMWV. The data for MOE 3 were taken from the Engagement Range Analysis Report portion of the postprocessing files. This report lists the average range of shots fired and the average range from which all kills were achieved. The Engagement Range Analysis Report also lists the BMP-2 and T-72 data separately. These two lists were combined to form one list containing the average range from which the Blue force killed either a BMP-2 or a T-72 target to form a total average kill range for MOE 3. Tables 1 through 3 show the summarized data sets used for analysis of each MOE.

As stated in Chapter I, the goal of this thesis is to assess whether the results of the simulation indicate that the proposed CM is more effective than the existing TOW 2B missile system and whether the difference in performance between CM and TOW 2B is affected by varying terrain conditions. The next chapter provides a statistical analysis of the simulation data to determine if there is a significant difference in performance between the TOW 2B and CM systems and discusses the possible causes for difference in performance.

| Run | TOW 2B Desert (228) | CM Desert (238) | TOW 2B Europe (229) | CM Europe (239) | TOW 2B Med. (230) | CM Med. (240) |
|---|---|---|---|---|---|---|
| 1 | 13 | 19 | 14 | 23 | 18 | 32 |
| 2 | 8 | 25 | 13 | 29 | 18 | 29 |
| 3 | 11 | 20 | 15 | 27 | 15 | 32 |
| 4 | 5 | 19 | 21 | 30 | 23 | 32 |
| 5 | 5 | 22 | 14 | 30 | 24 | 32 |
| 6 | 14 | 23 | 14 | 30 | 18 | 32 |
| 7 | 15 | 22 | 19 | 29 | 17 | 32 |
| 8 | 13 | 22 | 13 | 30 | 18 | 32 |
| 9 | 10 | 22 | 14 | 27 | 23 | 32 |
| 10 | 7 | 23 | 19 | 28 | 19 | 32 |
| 11 | 14 | 24 | 14 | 30 | 19 | 32 |
| 12 | 12 | 22 | 12 | 27 | 23 | 32 |
| 13 | 11 | 22 | 14 | 30 | 18 | 30 |
| 14 | 9 | 21 | 10 | 31 | 16 | 32 |
| 15 | 9 | 29 | 16 | 27 | 17 | 32 |
| 16 | 9 | 18 | 14 | 26 | 18 | 32 |
| 17 | 9 | 18 | 17 | 31 | 15 | 30 |
| 18 | 11 | 23 | 13 | 28 | 18 | 32 |
| 19 | 5 | 22 | 12 | 27 | 18 | 32 |
| 20 | 3 | 22 | 11 | 22 | 20 | 31 |
| 21 | 13 | 22 | 15 | 29 | 17 | 32 |
| 22 | 12 | 21 | 6 | 32 | 19 | 31 |
| 23 | 11 | 21 | 20 | 31 | 16 | 32 |
| 24 | 14 | 23 | 14 | 31 | 12 | 30 |
| 25 | 15 | 19 | 25 | 29 | 16 | 32 |

Table 1. Data Set for MOE 1 - Lethality – Number of Red Kills

| Run | TOW 2B Desert (228) | CM Desert (238) | TOW 2B Europe (229) | CM Europe (239) | TOW 2B Med. (230) | CM Med. (240) |
|---|---|---|---|---|---|---|
| 1 | 12 | 7 | 12 | 12 | 12 | 2 |
| 2 | 12 | 2 | 12 | 12 | 12 | 2 |
| 3 | 11 | 6 | 12 | 12 | 12 | 2 |
| 4 | 12 | 6 | 12 | 8 | 12 | 2 |
| 5 | 12 | 5 | 11 | 8 | 12 | 1 |
| 6 | 12 | 4 | 11 | 8 | 12 | 3 |
| 7 | 12 | 5 | 12 | 9 | 11 | 2 |
| 8 | 12 | 3 | 12 | 9 | 12 | 3 |
| 9 | 12 | 4 | 12 | 11 | 12 | 2 |
| 10 | 12 | 3 | 12 | 10 | 12 | 3 |
| 11 | 12 | 2 | 12 | 8 | 12 | 2 |
| 12 | 12 | 4 | 12 | 12 | 12 | 2 |
| 13 | 12 | 3 | 11 | 8 | 12 | 9 |
| 14 | 12 | 3 | 11 | 8 | 12 | 5 |
| 15 | 12 | 3 | 12 | 11 | 12 | 4 |
| 16 | 12 | 5 | 12 | 12 | 12 | 3 |
| 17 | 12 | 5 | 12 | 10 | 12 | 9 |
| 18 | 12 | 5 | 11 | 12 | 12 | 4 |
| 19 | 12 | 3 | 12 | 11 | 12 | 2 |
| 20 | 12 | 5 | 12 | 12 | 12 | 6 |
| 21 | 12 | 4 | 12 | 10 | 12 | 3 |
| 22 | 12 | 4 | 12 | 6 | 12 | 6 |
| 23 | 12 | 3 | 11 | 8 | 12 | 6 |
| 24 | 12 | 5 | 11 | 8 | 12 | 4 |
| 25 | 12 | 5 | 11 | 8 | 12 | 2 |

Table 2. Data Set for MOE 2 – Survivability – Number of Blue Losses

| Run | TOW 2B Desert (228) | CM Desert (238) | TOW 2B Europe (229) | CM Europe (239) | TOW 2B Med. (230) | CM Med. (240) |
|---|---|---|---|---|---|---|
| 1 | 2.679 | 4.608 | 1.697 | 2.981 | 2.729 | 4.271 |
| 2 | 2.794 | 4.679 | 1.512 | 3.186 | 2.789 | 4.433 |
| 3 | 2.630 | 4.671 | 1.608 | 3.472 | 2.785 | 4.242 |
| 4 | 2.528 | 4.562 | 1.608 | 3.399 | 2.747 | 4.286 |
| 5 | 2.528 | 4.615 | 1.337 | 3.399 | 2.762 | 4.273 |
| 6 | 2.779 | 4.753 | 1.337 | 3.140 | 2.732 | 4.096 |
| 7 | 2.598 | 4.624 | 1.751 | 3.159 | 2.725 | 4.433 |
| 8 | 2.679 | 4.649 | 0.978 | 3.208 | 2.729 | 4.236 |
| 9 | 2.777 | 4.730 | 1.370 | 3.296 | 2.747 | 4.271 |
| 10 | 2.799 | 4.643 | 1.751 | 3.290 | 2.772 | 4.093 |
| 11 | 2.710 | 4.653 | 1.370 | 3.086 | 2.780 | 4.653 |
| 12 | 2.726 | 4.578 | 0.921 | 2.948 | 2.747 | 4.578 |
| 13 | 2.714 | 4.797 | 1.429 | 3.016 | 2.729 | 4.797 |
| 14 | 2.678 | 4.699 | 1.372 | 3.231 | 2.748 | 4.699 |
| 15 | 2.678 | 4.643 | 1.394 | 3.293 | 2.676 | 4.643 |
| 16 | 2.678 | 4.560 | 1.724 | 3.037 | 2.721 | 4.560 |
| 17 | 2.670 | 4.560 | 1.419 | 3.025 | 2.698 | 4.560 |
| 18 | 2.630 | 4.735 | 1.645 | 3.243 | 2.732 | 4.735 |
| 19 | 2.528 | 4.669 | 0.921 | 3.293 | 2.721 | 4.669 |
| 20 | 2.598 | 4.653 | 1.397 | 3.282 | 2.714 | 4.653 |
| 21 | 2.453 | 4.730 | 1.608 | 3.303 | 2.725 | 4.730 |
| 22 | 2.725 | 4.698 | 1.590 | 3.027 | 2.768 | 4.698 |
| 23 | 2.734 | 4.791 | 1.459 | 3.073 | 2.748 | 4.791 |
| 24 | 2.710 | 4.735 | 1.327 | 3.231 | 2.614 | 4.735 |
| 25 | 2.766 | 4.562 | 1.624 | 3.086 | 2.696 | 4.562 |

Table 3. Data Set for MOE 3 – Average Range of Engagement

# VI. DATA ANALYSIS AND INTERPRETATION

The data presented in Chapter V were analyzed using simple, well-known statistical techniques. Graphical and numerical analyses of simulation results, showing the MOE performance of CM and TOW 2B in each geographic location, are contained in the following paragraphs. This analysis was facilitated by the use of a commercially available statistical software package [Ref. 9]. Additional analysis of the simulation was performed via real time and rerun viewing of the simulation battle. Several observations were made during the conduct of the simulation that provided an assessment of the results in addition to the quantitative analysis of the simulation output data. Presented first are analyses of the side-by-side results of CM and TOW 2B for each MOE and summary descriptive statistics. This is followed by a description of visual observations and an interpretation of the effects of geographic location on the simulation results.

## A. MOE 1 – LETHALITY

### 1. Graphical Analysis

A graphical approach was used for initial comparison between the simulation results. Figures 11 and 12 show side-by-side box-plots of the data. The box-plot provides a quick impression of the distribution of the data by graphically showing the central location and scatter/dispersion of the data from the simulation runs. The notched box shows non-parametric statistics of the median, lower and upper quartiles, and confidence interval around the median. The box shows the Inter-Quartile Range (IQR), which contains the central 50 percent of the sample distribution. The vertical bar and notch, within the box, show the median and 95 percent confidence interval of the median respectively. The dotted line connects the nearest observations within 1.5 (IQRs) of the lower and upper quartiles. Crosses (+) and circles (o) indicate possible outliers. Circles indicate near outlier observations of more than 1.5 IQRs from the quartiles. Crosses

indicate far outlier observations of more than 3.0 IQRs from the quartiles. The bracket beside the boxes shows parametric statistics of the mean, confidence interval around the mean and the 95 percentile range. Figures 9 and 10 provide a graphical description of the box-plot format.

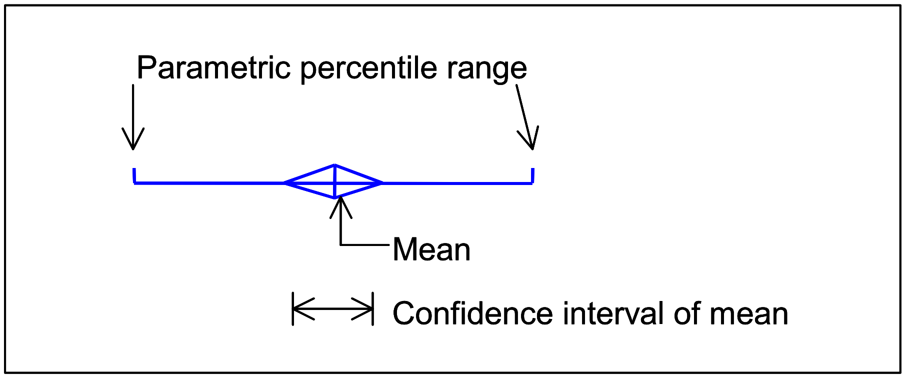


Figure 9. Parametric Statistics Legend

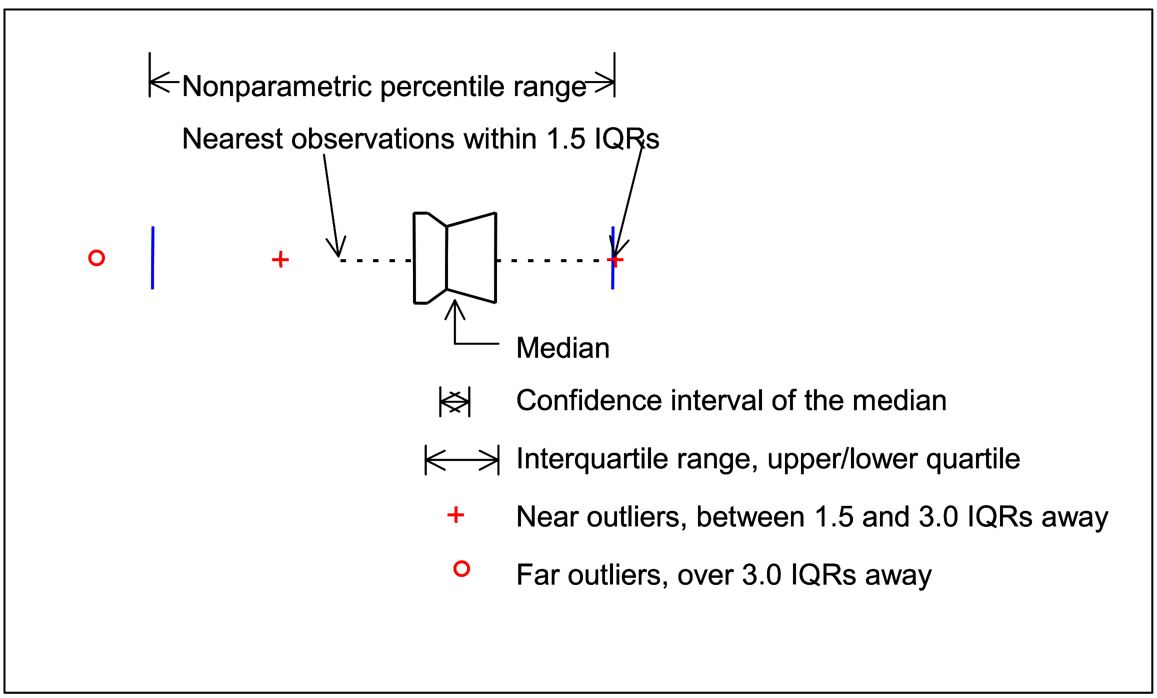


Figure 10. Non-parametric Statistics Legend

As stated in Chapter III, lethality is defined as the number of Red vehicle kills. To facilitate this analysis, the simulation data are graphically presented using two different methods. The first method shows the unadjusted simulation results of each missile in each terrain plotted side-by-side in Figure 11. The second method provides a closer look at performance variations between each terrain. With the second method, the differences between CM and TOW 2B performance were calculated, for each run in each location. Side-by-side box plots showing these performance differences are presented in Figure 12. The graphical analysis of lethality shows that the improvement of CM over TOW 2B is fairly consistent over the three terrain locations.

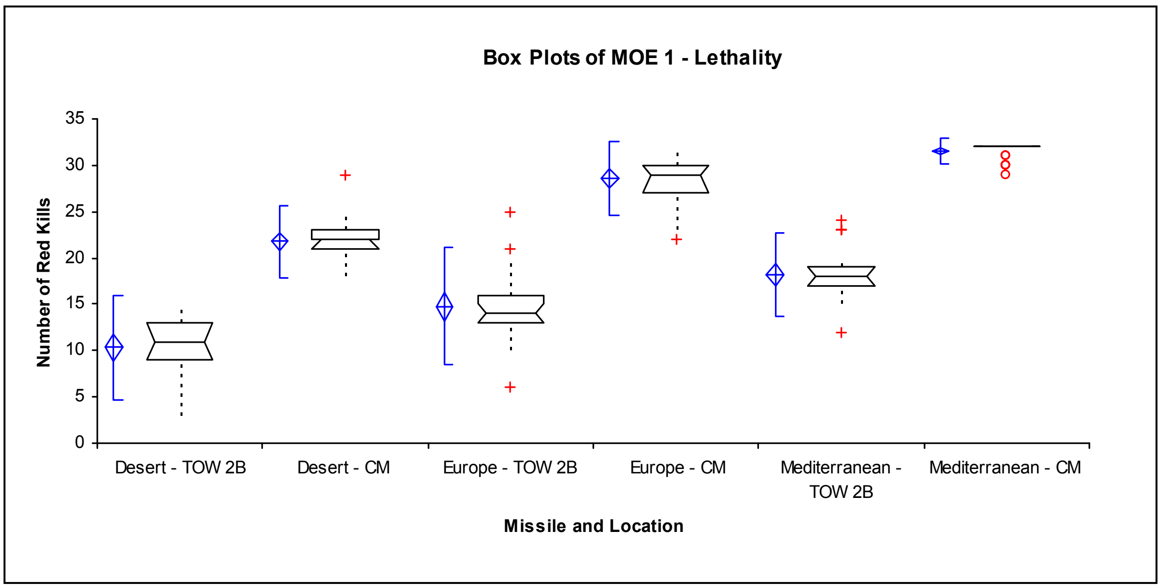


Figure 11. Side-by-Side Box Plots of MOE 1

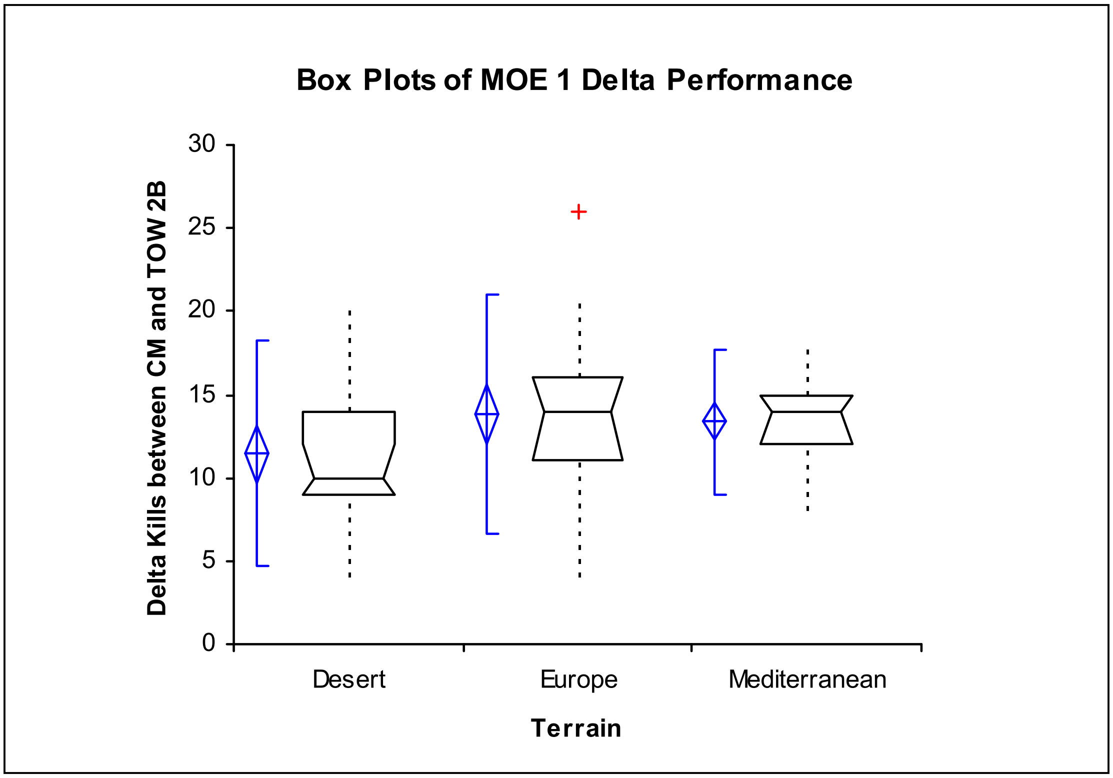


Figure 12. Side-by-Side Box Plots of MOE 1 Delta Performance of CM over TOW 2B

## 2. Descriptive Statistics

In addition to graphical analysis, descriptive statistics of the mean, standard deviation and range, were calculated for each group of simulation data. Table 4 provides a summary of these statistics for MOE 1.

| MOE 1 - Lethality (Red Kills) | | | | | | |
|---|---|---|---|---|---|---|
| | TOW 2B Desert | CM Desert | TOW 2B Europe | CM Europe | TOW 2B Med. | CM Med. |
| **Mean (# of kills)** | 10.32 | 21.76 | 14.76 | 28.56 | 18.20 | 31.56 |
| **Std Dev (# of kills)** | 3.3877 | 5.4400 | 3.8544 | 2.4338 | 2.7839 | 0.8699 |
| **Range (# of kills)** | 3-15 | 18-29 | 6-25 | 22-32 | 12-24 | 29-32 |

Table 4. Descriptive Statistics for MOE 1.

The analysis of the simulation data collected for MOE 1 shows the performance of the CM is significantly better than the performance of the TOW 2B in all three terrain types. The European terrain shows the largest mean improvement with an increase of 13.8 (94% improvement) Red kills and the Mediterranean terrain is a close second with an increase of 13.36 (73% improvement) Red kills. The Desert terrain shows a slightly smaller improvement of 11.44 kills, but a significant 111% improvement, on average, for CM over TOW 2B.

### 3. Visual Observations and Interpretation

The results of MOE 1 are probably affected by the fact that CM in the Mediterranean scenario almost always reached the maximum possible Red kills of 32 vehicles, and therefore could not do better. It is likely that the performance improvement of CM in Mediterranean terrain would be greater if the Red force were larger. Another factor possibly affecting the number of Red kills is the size of the engagement areas. Rugged landscape reduced the desert terrain engagement area. The Blue force was positioned on a ridge that provided a standoff range between the Blue and Red force thus limiting the time that the Blue force could engage the Red targets. In the European scenario, the Red force was passing by the Blue force in close proximity allowing continued engagement.

## B. MOE 2 – SURVIVABILITY

### 1. Graphical Analysis

As stated in Chapter III, survivability is defined as the number of Blue vehicles killed during battle. Side-by-side box plots, as described in paragraph 1, for MOE 2 simulation data are shown in Figures 13 and 14. MOE 2 shows a more pronounced difference in improvement of survivability between the three terrain locations.

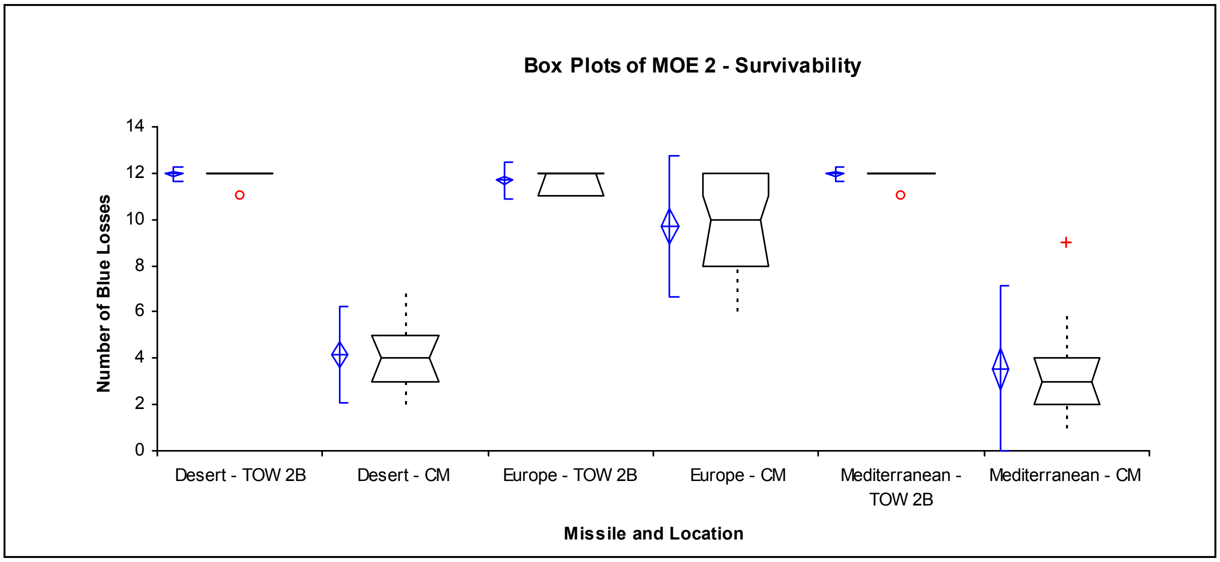


Figure 13. Side-by-Side Box Plots of MOE 2

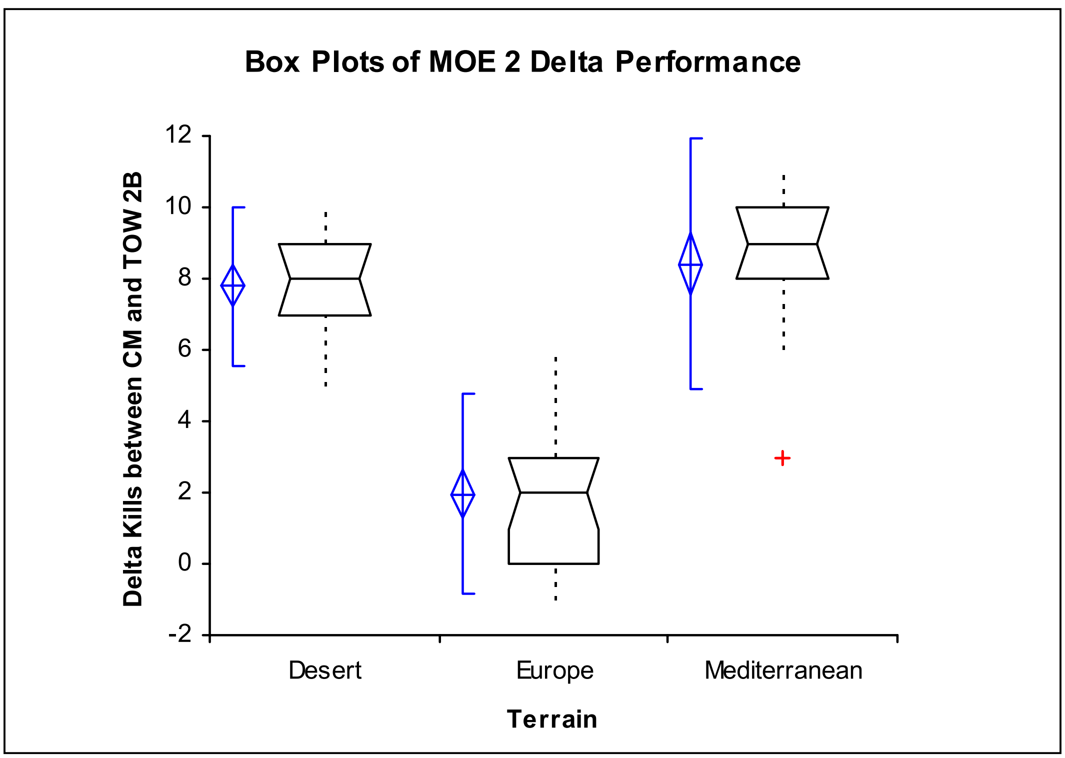


Figure 14. Side-by-Side Box Plots of MOE 2 Delta Performance of CM over TOW 2B

### 2. Descriptive Statistics

The analysis of the simulation data collected for MOE 2 shows the performance of the CM is better than the performance of the TOW 2B in all three terrain types. The Mediterranean terrain shows the largest mean improvement with a decrease of 8.4 (70%) Blue losses followed closely by the Desert terrain with a decrease of 7.8 (65%) Blue losses. The CM provides much less improvement over the TOW 2B in the European terrain with an average of 1.96 (17%) less Blue losses. A summary of the descriptive statistics for MOE 2 is shown in Table 5.

| MOE 2 - Survivability (Blue Losses) | | | | | | |
|---|---|---|---|---|---|---|
| | TOW 2B Desert | CM Desert | TOW 2B Europe | CM Europe | TOW 2B Med. | CM Med. |
| Mean (# of losses) | 11.96 | 4.16 | 11.68 | 9.72 | 11.96 | 3.56 |
| Std Dev (# of losses) | 0.2000 | 1.2806 | 0.4761 | 1.8601 | 0.0400 | 2.1618 |
| Range (# of losses) | 11-12 | 2-7 | 11-12 | 6-12 | 11-12 | 1-9 |

Table 5. Descriptive Statistics for MOE 2.

### 3. Visual Observations and Interpretation

It appears that the two factors affecting the performance results of MOE 1 also impacted MOE 2. CM almost always achieved the maximum possible Red kills, of 32 vehicles, in the Mediterranean terrain. This had a positive impact on survivability for CM because there were less Red vehicles left in the battle to kill the Blue force. It appears that engagement area also had an effect on survivability. The continued engagement seen in the European terrain increased the number of Blue kills even though there was also an increase in the number of Red kills, as discussed in MOE 1. Even though the CM showed the largest improvement in Red kills in the European scenario, there were still Red vehicles left to kill Blue targets. CM achieved 30 to 32 Red kills in some runs. In these runs, the number of Blue kills was somewhat lower. This caused a slight bimodal distribution that shows up as a wider variation in the MOE 2 box plots.

For the desert terrain, the large standoff, which reduced the engagement area, appeared to be a factor improving the Blue survivability. The Red force had less opportunity to engage Blue targets, which resulted in fewer Blue losses.

## C. MOE 3 – ENGAGEMENT RANGE

### 1. Graphical Analysis

As stated in Chapter III, engagement range is measured as the average range of Blue shots that kill Red vehicles. Side-by-side box plots, as described in paragraph 1, for MOE 3 simulation results are shown in Figure 15 and 16. The graphical analysis of lethality shows that the improvement of CM over TOW 2B is slightly different over the three terrain locations. An additional feature in Figure 12 is a horizontal line depicting the maximum range (as modeled) of both TOW 2B and CM. This shows that the full range capability of CM (6 kilometers) was never utilized in any of the scenarios. Also, the average engagement range of CM in the European terrain was less than the maximum range of TOW 2B (3.75 kilometers).

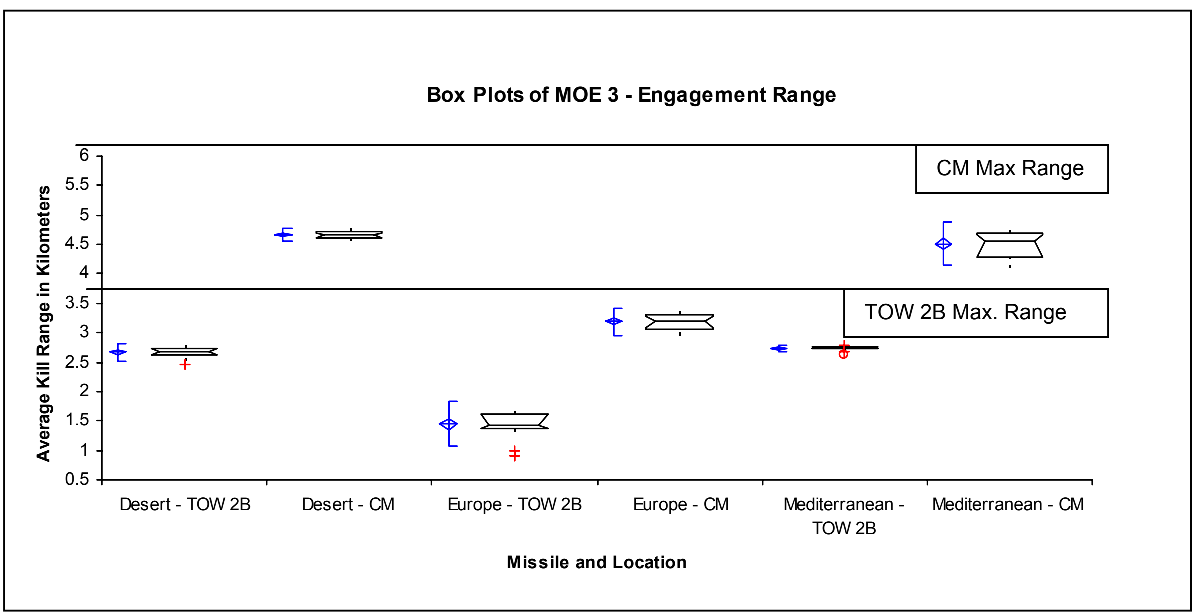


Figure 15. Side-by-Side Box Plots of MOE 3

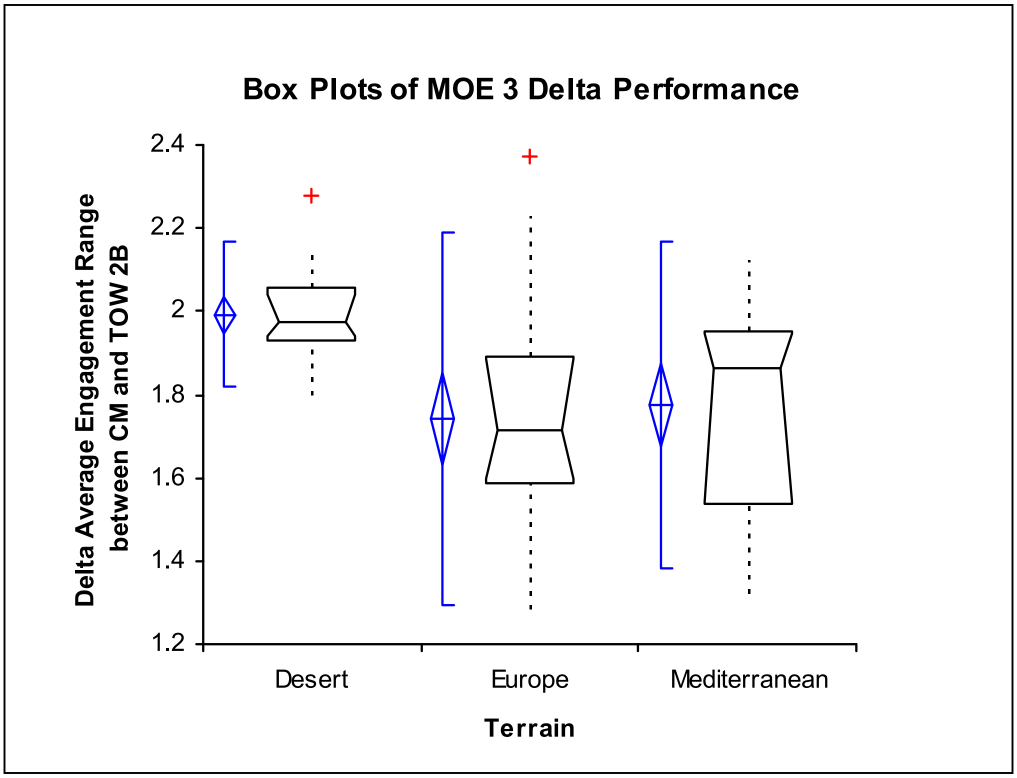


Figure 16. Side-by-Side Box Plots of MOE 3 Delta Performance

### 2. Descriptive Statistics

The analysis of the simulation data collected for MOE 3 shows the performance of the CM is significantly better than the performance of the TOW 2B in all three terrain types. The Desert terrain shows the largest mean improvement with an increase in average engagement of 1.9923 (75% increase) kilometers. The Mediterranean terrain showed a mean improvement of 1.7745 (65% increase) kilometers.. The European terrain shows the least mean increase with an average improvement of 1.7422 kilometers, but had the greatest percentage improvement with 120% increase in average engagement range. A summary of the descriptive statistics for MOE 3 is shown in Table 6.

| MOE 3 - Average Engagement Range | | | | | | |
|---|---|---|---|---|---|---|
| | TOW 2B Desert | CM Desert | TOW 2B Europe | CM Europe | TOW 2B Med. | CM Med. |
| Mean (kilometers) | 2.6716 | 4.6639 | 1.4460 | 3.1882 | 2.7334 | 4.5079 |
| Std Dev (kilometers) | 0.09161 | 0.07116 | 0.23567 | 0.14223 | 0.03736 | 0.22386 |
| Range (kilometers) | 2.614-2.789 | 4.096-4.797 | .0921-1.751 | 2.948-3.472 | 2.453-2.794 | 4.560-4.797 |

Table 6. Descriptive Statistics for MOE 3.

### 3. Visual Observations and Interpretation

Overall, MOE 3 shows a consistent improvement of CM over TOW 2B. This is a logical conclusion since the missile's maximum range increases from 3.75 kilometers to 6 kilometers (as modeled in this simulation experiment) between TOW 2B and CM. Additionally, the desert terrain provides greater visibility and less in-flight obstructions, than the European and Mediterranean terrains, allowing the greatest use of the CM increased range capability. The European terrain showed the least improvement. This is also logical since the European terrain contained the most obstructions with heavily wooded areas.

## D. SUMMARY

The analysis of the simulation data shows that CM is more effective than TOW 2B for all three MOEs in all three geographical locations. Table 7 summarizes the average improvement of CM over TOW 2B for each MOE in each terrain with green depicting the terrain showing the greatest improvement within a MOE, yellow the middle improvement, and red the least improvement. Of all the results, MOE 2 - survivability in the European terrain showed the least improvement. Improvement is largest overall in the Mediterranean terrain with the greatest improvement in MOE 2 – survivability and the second greatest improvement in both MOE 1 – lethality and MOE 3 – engagement range. It is possible that this is due to the fact that the Mediterranean terrain provides

reasonable visibility yet some coverage, with moderate vegetation. The Desert terrain with its minimal vegetation provided high visibility that in turn allowed maximum engagement range, but the rugged terrain reduced the engagement area and restricted the improvement of CM lethality. The Desert terrain's high visibility may have also allowed the Red forces to detect and destroy the Blue targets. Decreased Blue survivability is closely tied to decreased number of Red kills. These factors caused the Desert scenario to yield lower performance improvements in lethality and survivability than the Mediterranean scenario.

| | Desert | Europe | Mediterranean |
|---|---|---|---|
| **MOE 1** (Increased Red kills) | 11.44 | 13.80 | 13.36 |
| **MOE 2** (Decreased Blue losses) | 7.80 | 1.96 | 8.40 |
| **MOE 3** (Increased Engagement Range) | 1.9923 | 1.7422 | 1.7745 |

Table 7. Summary of Performance Improvement of CM over TOW 2B

The European terrain shows the least overall improvement due to the fact that the rugged, dense vegetation terrain reduces the line of sight and forces a closer combat situation. Red and Blue forces must be closer before detection and engagement because of the many obstructions. This offsets the range advantage provided by the CM. Improvement in the European terrain was still significant even though it was less than in the Desert and Mediterranean locations.

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# VII. CONCLUSIONS AND RECOMMENDATIONS

## A. CONCLUSIONS

Modeling and simulation can be used as a tool early in the acquisition process to predict the capabilities of proposed new weapon systems. Janus is an existing combat simulation that can be used to model new, as well as existing, close combat missile systems. The Janus simulation provides many analysis benefits in early acquisition with the ability to create realistic combat scenarios on various terrains. This provides an improvement over physical testing in the evaluation capability throughout the acquisition life cycle and can allow system developers to make more educated programmatic decisions in early development. Modeling and simulation have some limitations that should also be considered. The ability to accurately model these missile systems is heavily dependent upon correctly defining the missile characteristics in the Janus database. The results of this thesis are somewhat limited by the use of unclassified missile system performance parameters, as well as estimated rather than proven CM capability. The outcome of the simulation experiment is also very dependent upon the force structure, both friendly and opposing, and the set up of the scenarios. This thesis studied three realistic scenarios; however there are many more equally realistic scenarios yet to be tested.

The analysis of the simulation data shows that CM is more effective than TOW 2B for all three MOEs for all three geographical locations. This is a logical conclusion for the Desert and Mediterranean terrains since the CM, as modeled, has a 60 percent greater range. Both the Desert and Mediterranean terrains allow the use of increased range with their more open environment. The European terrain provides less opportunity to utilize increased missile range capability because there are many more obstacles, such as dense vegetation and mountains, that limit vision and missile flight. This forces a

closer combat situation. Improvement in the European terrain was still significant even with the closer engagement scenario.

The variations in performance improvement of CM over TOW 2B can largely be attributed to both the force structure and the scenario arrangement, in addition to the previously mentioned terrain conditions. The full variations in performance were limited in several cases by the fact that either all Blue or all Red forces were killed. Having a larger force structure would probably alter the simulation results. The simulation results also showed that force positions and movements, in addition to the terrain, can have an effect on the battle outcome. For example, the size of the engagement area can impact the simulation results.

All of these issues and limitations can be addressed by performing additional simulation experiments. The Janus database contains many more terrain map files. Janus also provides the flexibility of varying the elements of the force structure and the force structure size. These factors can be used to provide a more complete indication of overall missile system performance.

## B. RECOMMENDATIONS

Several recommendations are made as a result of the simulation and analysis involved in this thesis. The first recommendation is that the Janus database be updated with more accurate performance information for CM, as it becomes known. As the CM continues through development, its performance will become better known and proven through physical testing. Rerunning the simulation with these performance parameters, in parallel with development, will increase the accuracy and confidence of the simulation results.

The second recommendation is to perform the simulation on more terrain sets and with differing force structures. These scenarios can be developed with knowledge of emerging and projected threat situations. This applies to the terrain location, opposing target types, force size, and enemy tactics. Additional terrains are available in the Janus database or new digital terrain files can be loaded into the database. The opposing target types should be updated to reflect current threats. T-72s and BMP-2s were used as a baseline opposition force for this simulation, but CM should be evaluated against more advanced threats such as T-80s and BMP-3s. Janus allows easy modification of force size and movements to reflect alternate engagement scenarios.

Finally, this simulation capability can be used to support CM design tradeoff analysis. The results of this thesis shows that increased missile range provides significant improvement across varying terrain conditions, but this thesis did not perform a sensitivity analysis to determine the point of diminishing returns. Increasing missile range will provide increased effectiveness up to a point at which increased range provides no more or very little benefits. At this point, it does not make sense to spend development money and effort improving the missile range. Janus can be used as a tool to determine performance break points, thus reducing missile development cost.

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# APPENDIX A. BLUE SYSTEMS DATABASE

This appendix shows the Blue System performance parameters that were entered into Janus prior to conducting simulation runs.

BLUE SYSTEMS GENERAL CHARACTERISTICS

| Sys Num | Sys Name | Max Rd Speed (Km/hr) | Max Visbl (Km) | Wpn Rng (Km) | Sens Hght (m) | Crew Size | Elemt Space (m) | Chem Xmit Fctr | Gra Sym | Cls Sym | Host Cap |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 90 | GNDCM | 60 | 7.0 | 6.0 | 3 | 4 | 100 | 1.00 | 32 | 127 | 1 |
| 92 | Sys 92 | 60 | 6.0 | 3.0 | 3 | 4 | 100 | 1.00 | 32 | 127 | 1 |

BLUE SYSTEM FUNCTIONAL CHARACTERISTICS

| Sys Num | Sys Name | Lsr Dsg | Min Dsp | Eng Typ | Fir Cat | Fly Typ | Log Typ | Mov Typ | Rdr Typ | Smk Dsp | Srv Typ | Swm Typ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 90 | GNDCM | 1 | | 4 | 1 | | | 2 | | 2 | | |
| 92 | Sys 92 | 1 | | 4 | 1 | | | 2 | | 2 | | |

BLUE SYSTEMS DETECTION DATA

| | | DETECT Dimensions (Meters) | | | SENSORS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Sys Num | Sys Name | Lngth | Width | Hght | Prim | Alt | Defil | Popup | BCIS Type | BCIS Func |
| 90 | GNDCM | 5.42 | 2.86 | 2.81 | 23 | | 1 | | | |
| 92 | Sys 92 | 5.42 | 2.86 | 2.81 | 23 | | 1 | | | |

OPTICAL AND THERMAL CONTRAST DATA

| | | Thermal Contrast | |
|---|---|---|---|
| Sys Num | Optical Contrast | Exposed | Defilade |
| 90 | 0.360 | 2.000 | 0.500 |
| 92 | 0.360 | 2.000 | 0.500 |

SENSOR FIELD of VIEW (FOV) and BAND

| Sensor Number | FOV-(Degrees) Narrow | Wide | Narrow-to-Wide Factor | Specral Band | (1,2 = Optical 3,4 = Thermal) |
|---|---|---|---|---|---|
| 23 | 15.00 | | | 1 | |
| 2 | 9.00 | 15.00 | 0.60000 | 3 | |

CYCLES per MILLIRADIAN versus TEMPERATURE or CONTRAST
Sensor Number: 23

| Pair | Cycles | TMP/CON | Pair | Cycles | TMP/CON |
|---|---|---|---|---|---|
| 1 | 0.000 | 0.020 | 11 | 10.620 | 0.400 |
| 2 | 3.816 | 0.030 | 12 | 10.950 | 0.450 |
| 3 | 4.776 | 0.040 | 13 | 11.256 | 0.500 |
| 4 | 5.400 | 0.050 | 14 | 11.544 | 0.550 |
| 5 | 7.128 | 0.100 | 15 | 11.814 | 0.600 |
| 6 | 8.112 | 0.150 | 16 | 12.072 | 0.650 |
| 7 | 8.814 | 0.200 | 17 | 12.318 | 0.700 |
| 8 | 9.378 | 0.250 | 18 | 12.792 | 0.800 |
| 9 | 9.846 | 0.300 | 19 | 13.248 | 0.900 |
| 10 | 10.254 | 0.350 | 20 | 13.686 | 1.000 |

CYCLES per MILLIRADIAN versus TEMPERATURE or CONTRAST
Sensor Number: 2

| Pair | Cycles | TMP/CON | Pair | Cycles | TMP/CON |
|---|---|---|---|---|---|
| 1 | 0.225 | 0.050 | 11 | 0.709 | 0.410 |
| 2 | 0.311 | 0.075 | 12 | 0.750 | 0.540 |
| 3 | 0.363 | 0.080 | 13 | 0.773 | 0.600 |
| 4 | 0.407 | 0.090 | 14 | 0.803 | 0.750 |
| 5 | 0.450 | 0.100 | 15 | 0.833 | 0.900 |
| 6 | 0.494 | 0.150 | 16 | 0.863 | 1.050 |
| 7 | 0.539 | 0.200 | 17 | 0.891 | 1.200 |
| 8 | 0.583 | 0.250 | 18 | 0.919 | 1.300 |
| 9 | 0.626 | 0.300 | 19 | 0.947 | 1.400 |
| 10 | 0.668 | 0.370 | 20 | 0.975 | 2.000 |

WEAPONS/ORDNANCE for BLUE system TOW 2B

| Wpn/Ord Number Relative (1-15) | Absolute (1-250) | Wpn/Ord Name | Basic Load | Upload Time (Minutes) | Rel Wpn/Ord to use if Ammo Expended (1-15) |
|---|---|---|---|---|---|
| 13 | 5 | TOW | 7 | 2.0 | |

WEAPONS/ORDNANCE for BLUE system CM

| Wpn/Ord Number Relative (1-15) | Absolute (1-250) | Wpn/Ord Name | Basic Load | Upload Time (Minutes) | Rel Wpn/Ord to use if Ammo Expended (1-15) |
|---|---|---|---|---|---|
| 13 | 90 | CM DF | 7 | 2.0 | |

BLUE WEAPON/ROUND CHARACTERISTICS

| Wpn Num | Wpn Name | Lay Time (Sec) | Aim Time (Sec) | Reload Time (Sec) | Rnds / Trggr Pull | Trggr Pulls / Reload | Round Speed (Km/Sec) | Min. SSKP |
|---|---|---|---|---|---|---|---|---|
| 5 | TOW 2B | 7.0 | 6.0 | 38.0 | 1 | 7 | 0.180 | 5 |
| 90 | CM DF | 6.0 | 6.0 | 60.0 | 1 | 7 | 0.400 | 5 |

BLUE WEAPON/ROUND GUIDANCE DATA

Fire on: 0 = Yes, no restrictions. 1 = Stop, can move before impact
the Move: 3 = Reduce speed to fire. 2 = Stop, only move after impact

| Wpn Num | Wpn Name | Guidance Mode | Fire on the Move | On-Board Sensor | Critical Altitude (meters) |
|---|---|---|---|---|---|
| 5 | TOW 2B | 1 | 2 | | |
| 90 | CM DF | | 1 | 2 | |

HIT and KILL DATA SET Numbers for BLUE Weapon TOW 2B

| RED Target Sys Num | RED Target Sys Name | PH Data Set | PK Data Set |
|---|---|---|---|
| 389 | T72 | 509 | 509 |
| 397 | BMP-2 | 511 | 511 |

HIT and KILL DATA SET Numbers for BLUE Weapon TOW 2B

| RED Target Sys Num | RED Target Sys Name | PH Data Set | PK Data Set |
|---|---|---|---|
| 389 | T72 | 100 | 100 |
| 397 | BMP-2 | 100 | 100 |

PROBABILITY of HIT Data Set: 0509

| Range(m)--> | 500 | 1313 | 2125 | 2938 | 3750 |
|---|---|---|---|---|---|
| Posture: | | | | | |
| SSDF | 0.95000 | 0.95000 | 0.95000 | 0.95000 | 0.95000 |
| SSDH | 0.95000 | 0.95000 | 0.95000 | 0.95000 | 0.95000 |
| SSEF | 0.95000 | 0.95000 | 0.95000 | 0.95000 | 0.95000 |
| SSEH | 0.95000 | 0.95000 | 0.95000 | 0.95000 | 0.95000 |
| SMDF (not used) | 0.95000 | 0.95000 | 0.95000 | 0.95000 | 0.95000 |
| SMDH (not used) | 0.95000 | 0.95000 | 0.95000 | 0.95000 | 0.95000 |
| SMEF | 0.95000 | 0.95000 | 0.95000 | 0.95000 | 0.95000 |
| SMEH | 0.95000 | 0.95000 | 0.95000 | 0.95000 | 0.95000 |
| MSDF | | | | | |
| MSDH | | | | | |
| MSEF | | | | | |
| MSEH | | | | | |
| MMDF (not used) | | | | | |
| MMDH (not used) | | | | | |
| MMEF | | | | | |
| MMEH | | | | | |

PROBABILITY of HIT Data Set: 0511

| Range(m)--> | 500 | 1313 | 2125 | 2938 | 3750 |
|---|---|---|---|---|---|
| Posture: | | | | | |
| SSDF | 0.95000 | 0.95000 | 0.95000 | 0.95000 | 0.95000 |
| SSDH | 0.95000 | 0.95000 | 0.95000 | 0.95000 | 0.95000 |
| SSEF | 0.95000 | 0.95000 | 0.95000 | 0.95000 | 0.95000 |
| SSEH | 0.95000 | 0.95000 | 0.95000 | 0.95000 | 0.95000 |
| SMDF (not used) | 0.95000 | 0.95000 | 0.95000 | 0.95000 | 0.95000 |
| SMDH (not used) | 0.95000 | 0.95000 | 0.95000 | 0.95000 | 0.95000 |
| SMEF | 0.95000 | 0.95000 | 0.95000 | 0.95000 | 0.95000 |
| SMEH | 0.95000 | 0.95000 | 0.95000 | 0.95000 | 0.95000 |
| MSDF | | | | | |
| MSDH | | | | | |
| MSEF | | | | | |
| MSEH | | | | | |
| MMDF (not used) | | | | | |
| MMDH (not used) | | | | | |
| MMEF | | | | | |
| MMEH | | | | | |

PROBABILITY of HIT Data Set: 0100

| Range(m)--> | 500 | 3000 | 6000 | 9000 | 12000 |
|---|---|---|---|---|---|
| Posture: | | | | | |
| SSDF | 0.94000 | 0.94000 | 0.94000 | 0.94000 | 0.94000 |
| SSDH | 0.94000 | 0.94000 | 0.94000 | 0.94000 | 0.94000 |
| SSEF | 0.94000 | 0.94000 | 0.94000 | 0.94000 | 0.94000 |
| SSEH | 0.94000 | 0.94000 | 0.94000 | 0.94000 | 0.94000 |
| SMDF (not used) | 0.94000 | 0.94000 | 0.94000 | 0.94000 | 0.94000 |
| SMDH (not used) | 0.94000 | 0.94000 | 0.94000 | 0.94000 | 0.94000 |
| SMEF | 0.94000 | 0.94000 | 0.94000 | 0.94000 | 0.94000 |
| SMEH | 0.94000 | 0.94000 | 0.94000 | 0.94000 | 0.94000 |
| MSDF | | | | | |
| MSDH | | | | | |
| MSEF | | | | | |
| MSEH | | | | | |
| MMDF (not used) | | | | | |
| MMDH (not used) | | | | | |
| MMEF | | | | | |
| MMEH | | | | | |

PROBABILITY of KILL Data Set: 0511

| Range(m)--> | 500 | 1313 | 2125 | 2938 | 3750 |
|---|---|---|---|---|---|
| Posture: | | | | | |
| M/ DF | 0.74800 | 0.75800 | 0.76680 | 0.78290 | 0.76800 |
| M/ DH | 0.74370 | 0.75390 | 0.77300 | 0.79760 | 0.78460 |
| M/ EF | 0.75900 | 0.76480 | 0.77150 | 0.77860 | 0.76800 |
| M/ EH | 0.76170 | 0.76590 | 0.77970 | 0.79200 | 0.78460 |

PROBABILITY of HIT Data Set: 0509

| Range(m)--> | 500 | 1313 | 2125 | 2938 | 3750 |
|---|---|---|---|---|---|
| Posture: | | | | | |
| M/ DF | 0.59900 | 0.63310 | 0.65380 | 0.66810 | 0.66400 |
| M/ DH | 0.55030 | 0.56440 | 0.56980 | 0.58140 | 0.57430 |
| M/ EF | 0.57500 | 0.61780 | 0.63880 | 0.65650 | 0.66400 |
| M/ EH | 0.55850 | 0.57780 | 0.59040 | 0.59110 | 0.57430 |

PROBABILITY of HIT Data Set: 0100

| Range(m)--> | 500 | 3000 | 6000 | 9000 | 12000 |
|---|---|---|---|---|---|
| Posture: | | | | | |
| M/ DF | 0.80000 | 0.80000 | 0.80000 | 0.80000 | 0.80000 |
| M/ DH | 0.80000 | 0.80000 | 0.80000 | 0.80000 | 0.80000 |
| M/ EF | 0.80000 | 0.80000 | 0.80000 | 0.80000 | 0.80000 |
| M/ EH | 0.80000 | 0.80000 | 0.80000 | 0.80000 | 0.80000 |

# APPENDIX B. RED SYSTEMS DATABASE

This appendix shows the Red Systems performance parameters that were entered into Janus prior to conducting simulation runs.

RED SYSTEMS GENERAL CHARACTERISTICS

| Sys Num | Sys Name | Max Rd Speed (Km/hr) | Max Visbl (Km) | Wpn Rng (Km) | Sens Hght (m) | Crew Size | Elemt Space (m) | Chem Xmit Fctr | Gra Sym | Cls Sym | Host Cap |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 389 | T72 | 60 | 6.0 | 5.0 | 2 | 3 | 50 | 1.00 | 66 | 122 | |
| 397 | BMP-2 | 60 | 6.0 | 4.0 | 2 | 4 | 100 | 1.00 | 67 | 123 | 2 |

RED SYSTEM FUNCTIONAL CHARACTERISTICS

| Sys Num | Sys Name | Lsr Dsg | Min Dsp | Eng Typ | Fir Cat | Fly Typ | Log Typ | Mov Typ | Rdr Typ | Smk Dsp | Srv Typ | Swm Typ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 389 | T72 | | | 3 | 1 | | | 2 | | 3 | | |
| 397 | BMP-2 | | | 4 | 1 | | | 2 | | 3 | | 1 |

RED SYSTEMS DETECTION DATA

| | | DETECT Dimensions (Meters) | | | SENSORS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Sys Num | Sys Name | Lngth | Width | Hght | Prim | Alt | Defil | Popup | BCIS Type | BCIS Func |
| 389 | T72 | 5.48 | 3.15 | 2.25 | 23 | 37 | 17 | 1 | | |
| 397 | BMP-2 | 4.90 | 2.79 | 2.02 | 23 | 37 | 17 | 1 | | |

OPTICAL AND THERMAL CONTRAST DATA

| | | Thermal Contrast | |
|---|---|---|---|
| Sys Num | Optical Contrast | Exposed | Defilade |
| 389 | 0.360 | 2.000 | 0.500 |
| 397 | 0.360 | 2.000 | 0.500 |

SENSOR FIELD of VIEW (FOV) and BAND

| Sensor Number | FOV-(Degrees) Narrow | Wide | Narrow-to-Wide Factor | Specral Band | (1,2 = Optical 3,4 = Thermal) |
|---|---|---|---|---|---|
| 23 | 15.00 | | | 1 | |
| 37 | 4.40 | 8.80 | 0.50000 | 4 | |
| 17 | 8.7 | | | 1 | |

CYCLES per MILLIRADIAN versus TEMPERATURE or CONTRAST

Sensor Number: 23

| Pair | Cycles | TMP/CON | Pair | Cycles | TMP/CON |
|---|---|---|---|---|---|
| 1 | 0.000 | 0.020 | 11 | 10.620 | 0.400 |
| 2 | 3.816 | 0.030 | 12 | 10.950 | 0.450 |
| 3 | 4.776 | 0.040 | 13 | 11.256 | 0.500 |
| 4 | 5.400 | 0.050 | 14 | 11.544 | 0.550 |
| 5 | 7.128 | 0.100 | 15 | 11.814 | 0.600 |
| 6 | 8.112 | 0.150 | 16 | 12.072 | 0.650 |
| 7 | 8.814 | 0.200 | 17 | 12.318 | 0.700 |
| 8 | 9.378 | 0.250 | 18 | 12.792 | 0.800 |
| 9 | 9.846 | 0.300 | 19 | 13.248 | 0.900 |
| 10 | 10.254 | 0.350 | 20 | 13.686 | 1.000 |

CYCLES per MILLIRADIAN versus TEMPERATURE or CONTRAST

Sensor Number: 17

| Pair | Cycles | TMP/CON | Pair | Cycles | TMP/CON |
|---|---|---|---|---|---|
| 1 | 0.000 | 0.020 | 11 | 14.280 | 0.400 |
| 2 | 5.184 | 0.030 | 12 | 14.728 | 0.450 |
| 3 | 6.472 | 0.040 | 13 | 15.136 | 0.500 |
| 4 | 7.304 | 0.050 | 14 | 15.520 | 0.550 |
| 5 | 9.616 | 0.100 | 15 | 15.880 | 0.600 |
| 6 | 10.928 | 0.150 | 16 | 16.224 | 0.650 |
| 7 | 11.872 | 0.200 | 17 | 16.552 | 0.700 |
| 8 | 12.616 | 0.250 | 18 | 17.184 | 0.800 |
| 9 | 13.248 | 0.300 | 19 | 17.792 | 0.900 |
| 10 | 13.792 | 0.350 | 20 | 18.384 | 1.000 |

CYCLES per MILLIRADIAN versus TEMPERATURE or CONTRAST

Sensor Number: 37

| Pair | Cycles | TMP/CON | Pair | Cycles | TMP/CON |
|---|---|---|---|---|---|
| 1 | 0.260 | 0.005 | 11 | 2.864 | 0.194 |
| 2 | 0.521 | 0.009 | 12 | 3.125 | 0.285 |
| 3 | 0.781 | 0.014 | 13 | 3.385 | 0.430 |
| 4 | 1.042 | 0.019 | 14 | 6.646 | 0.669 |
| 5 | 1.302 | 0.027 | 15 | 3.906 | 1.088 |
| 6 | 1.562 | 0.037 | 16 | 4.167 | 1.871 |
| 7 | 1.823 | 0.050 | 17 | 4.427 | 3.493 |
| 8 | 2.083 | 0.069 | 18 | 4.688 | 7.477 |
| 9 | 2.344 | 0.096 | 19 | 4.948 | 21.750 |
| 10 | 2.604 | 0.136 | 20 | 5.208 | 999.999 |

WEAPONS/ORDNANCE for RED system T72

Wpn/Ord Number

| Relative (1-15) | Absolute (1-250) | Wpn/Ord Name | Basic Load | Upload Time (Minutes) | Rel Wpn/Ord to use if Ammo Expended (1-15) |
|---|---|---|---|---|---|
| 10 | 378 | AT-11 | 6 | 2.0 | 13 |

WEAPONS/ORDNANCE for RED system BMP-2

Wpn/Ord Number

| Relative (1-15) | Absolute (1-250) | Wpn/Ord Name | Basic Load | Upload Time (Minutes) | Rel Wpn/Ord to use if Ammo Expended (1-15) |
|---|---|---|---|---|---|
| 1 | 391 | 2A42 30mm | 500 | 2.0 | |
| 3 | 371 | AT-5 | 4 | 2 | 1 |

RED WEAPON/ROUND CHARACTERISTICS

| Wpn Num | Wpn Name | Lay Time (Sec) | Aim Time (Sec) | Reload Time (Sec) | Rnds / Trggr Pull | Trggr Pulls / Reload | Round Speed (Km/Sec) | Min. SSKP |
|---|---|---|---|---|---|---|---|---|
| 371 | AT-5 | 7.0 | 7.0 | 40.0 | 1 | 7 | 0.270 | 5 |
| 378 | AT-11 | 6.9 | 3.0 | 10.0 | 1 | 7 | 0.350 | 5 |
| 391 | 2A42 30mm | 8.3 | 2.7 | 120.0 | 5 | 36 | 1.300 | 5 |

RED WEAPON/ROUND GUIDANCE DATA

Fire on: 0 = Yes, no restrictions. 1 = Stop, can move before impact
the Move: 3 = Reduce speed to fire. 2 = Stop, only move after impact

| Wpn Num | Wpn Name | Guidance Mode | Fire on the Move | On-Board Sensor | Critical Altitude (meters) |
|---|---|---|---|---|---|
| 371 | AT-5 | 2 | 2 | | |
| 378 | AT-11 | 2 | 1 | | |
| 391 | 2A42 30mm | | | | |

HIT and KILL DATA SET Numbers for RED Weapon AT-5

| BLUE Target Sys Num | BLUE Target Sys Name | PH Data Set | PK Data Set |
|---|---|---|---|
| 90 | GNDCM | 779 | 779 |
| 92 | Sys 92 (TOW) | 779 | 779 |

HIT and KILL DATA SET Numbers for RED Weapon AT-11

| BLUE Target Sys Num | BLUE Target Sys Name | PH Data Set | PK Data Set |
|---|---|---|---|
| 90 | GNDCM | 738 | 738 |
| 92 | Sys 92 (TOW) | 738 | 738 |

HIT and KILL DATA SET Numbers for RED Weapon 30mm

| BLUE Target Sys Num | BLUE Target Sys Name | PH Data Set | PK Data Set |
|---|---|---|---|
| 90 | GNDCM | 654 | 654 |
| 92 | Sys 92 (TOW) | 654 | 654 |

PROBABILITY of HIT Data Set: 738

| Range(m)--> | 250 | 1188 | 2125 | 3063 | 4000 |
|---|---|---|---|---|---|
| Posture: | | | | | |
| SSDF | 0.45750 | 0.45750 | 0.45750 | 0.45750 | 0.45750 |
| SSDH | 0.43830 | 0.43830 | 0.43830 | 0.43880 | 0.43830 |
| SSEF | 0.91640 | 0.91640 | 0.91640 | 0.91660 | 0.91640 |
| SSEH | 0.90480 | 0.90480 | 0.90480 | 0.90500 | 0.90480 |
| SMDF (not used) | 0.38260 | 0.38220 | 0.37790 | 0.37640 | 0.37480 |
| SMDH (not used) | 0.36000 | 0.35960 | 0.35520 | 0.35360 | 0.35200 |
| SMEF | 0.87540 | 0.87520 | 0.87210 | 0.87100 | 0.86990 |
| SMEH | 0.85410 | 0.85380 | 0.85000 | 0.84870 | 0.84730 |
| MSDF | | | | | |
| MSDH | | | | | |
| MSEF | | | | | |
| MSEH | | | | | |
| MMDF (not used) | | | | | |
| MMDH (not used) | | | | | |
| MMEF | | | | | |
| MMEH | | | | | |

PROBABILITY of HIT Data Set: 779

| Range(m)--> | 100 | 1075 | 2050 | 3025 | 4000 |
|---|---|---|---|---|---|
| Posture: | | | | | |
| SSDF | 0.46140 | 0.46130 | 0.46070 | 0.46220 | 0.46370 |
| SSDH | 0.44770 | 0.44770 | 0.44700 | 0.44860 | 0.45020 |
| SSEF | 0.91800 | 0.91790 | 0.91770 | 0.91830 | 0.91890 |
| SSEH | 0.90980 | 0.90980 | 0.90950 | 0.91020 | 0.91090 |
| SMDF (not used) | 0.35120 | 0.35120 | 0.35040 | 0.35210 | 0.35800 |
| SMDH (not used) | 0.32630 | 0.32630 | 0.32550 | 0.32720 | 0.32880 |
| SMEF | 0.86740 | 0.86740 | 0.86690 | 0.86800 | 0.86910 |
| SMEH | 0.81590 | 0.81590 | 0.81530 | 0.81660 | 0.81790 |
| MSDF | | | | | |
| MSDH | | | | | |
| MSEF | | | | | |
| MSEH | | | | | |
| MMDF (not used) | | | | | |
| MMDH (not used) | | | | | |
| MMEF | | | | | |
| MMEH | | | | | |

PROBABILITY of HIT Data Set: 654

| Range(m)--> | | 700 | 1400 | 2100 | 2800 |
|---|---|---|---|---|---|
| Posture: | | | | | |
| SSDF | 0.50150 | 0.27820 | 0.11330 | 0.60600 | 0.03490 |
| SSDH | 0.46780 | 0.25740 | 0.10420 | 0.05530 | 0.03050 |
| SSEF | 0.99230 | 0.92890 | 0.74700 | 0.54610 | 0.40100 |
| SSEH | 0.99020 | 0.91690 | 0.70530 | 0.50260 | 0.36020 |
| SMDF (not used) | 0.48250 | 0.22000 | 0.07850 | 0.03600 | 0.01790 |
| SMDH (not used) | 0.44920 | 0.20270 | 0.07170 | 0.03180 | 0.01670 |
| SMEF | 0.99120 | 0.89850 | 0.64250 | 0.42220 | 0.27690 |
| SMEH | 0.98830 | 0.87410 | 0.59420 | 0.37920 | 0.24610 |
| MSDF | 0.50150 | 0.27820 | 0.11330 | 0.60600 | 0.03490 |
| MSDH | 0.46780 | 0.25740 | 0.10420 | 0.05530 | 0.03050 |
| MSEF | 0.99230 | 0.92890 | 0.74700 | 0.54610 | 0.40100 |
| MSEH | 0.99020 | 0.91690 | 0.70530 | 0.50260 | 0.36020 |
| MMDF (not used) | 0.48250 | 0.22000 | 0.07850 | 0.03600 | 0.01790 |
| MMDH (not used) | 0.44920 | 0.20270 | 0.07170 | 0.03180 | 0.01670 |
| MMEF | 0.99120 | 0.89850 | 0.64250 | 0.42220 | 0.27690 |
| MMEH | 0.98830 | 0.87410 | 0.59420 | 0.37920 | 0.24610 |

PROBABILITY of KILL Data Set: 0738

| Range(m)--> | 500 | 1313 | 2125 | 2938 | 3750 |
|---|---|---|---|---|---|
| Posture: | | | | | |
| MOBDF | 0.98020 | 0.97980 | 0.98080 | 0.98080 | 0.98080 |
| MOBDH | 0.97860 | 0.97830 | 0.97910 | 0.97910 | 0.97910 |
| MOBEF | 0.98370 | 0.98330 | 0.98320 | 0.98440 | 0.98440 |
| MOBEH | 0.98820 | 0.98790 | 0.98780 | 0.98790 | 0.98790 |
| FRPDF | 0.98970 | 0.98940 | 0.99010 | 0.99010 | 0.99010 |
| FRPDH | 0.98880 | 0.98860 | 0.98920 | 0.98920 | 0.98920 |
| FRPEF | 0.97880 | 0.97820 | 0.97820 | 0.97810 | 0.97950 |
| FRPEH | 0.98170 | 0.98130 | 0.98120 | 0.98120 | 0.98260 |
| M/ DF | 0.98990 | 0.98950 | 0.99030 | 0.99030 | 0.99030 |
| M/ DH | 0.98900 | 0.98880 | 0.98940 | 0.98940 | 0.98940 |
| M/ EF | 0.98520 | 0.98480 | 0.98480 | 0.98580 | 0.98580 |
| M/ EH | 0.98980 | 0.98940 | 0.98930 | 0.98940 | 0.98940 |
| KK DF | 0.06200 | 0.06200 | 0.06200 | 0.06200 | 0.06200 |
| KK DH | 0.06200 | 0.06200 | 0.06200 | 0.06200 | 0.06200 |
| KK EF | 0.22360 | 0.21620 | 0.21530 | 0.23790 | 0.23760 |
| KK EH | 0.22420 | 0.21670 | 0.21590 | 0.23760 | 0.23730 |

PROBABILITY of KILL Data Set: 0779

| Range(m)--> | 500 | 1313 | 2125 | 2938 | 3750 |
|---|---|---|---|---|---|
| Posture: | | | | | |
| MOBDF | 0.97960 | 0.97960 | 0.97960 | 0.97960 | 0.97970 |
| MOBDH | 0.97820 | 0.97820 | 0.97820 | 0.97830 | 0.97830 |
| MOBEF | 0.98310 | 0.98310 | 0.98310 | 0.98310 | 0.98320 |
| MOBEH | 0.98650 | 0.98650 | 0.98650 | 0.98650 | 0.98650 |
| FRPDF | 0.98930 | 0.98930 | 0.98920 | 0.98930 | 0.98930 |
| FRPDH | 0.98870 | 0.98870 | 0.98870 | 0.98880 | 0.98880 |
| FRPEF | 0.97800 | 0.97800 | 0.97800 | 0.97800 | 0.97810 |
| FRPEH | 0.98090 | 0.98090 | 0.98090 | 0.98100 | 0.98090 |
| M/ DF | 0.98940 | 0.98940 | 0.98940 | 0.98940 | 0.98940 |
| M/ DH | 0.98890 | 0.98890 | 0.98890 | 0.98900 | 0.98890 |
| M/ EF | 0.98470 | 0.98470 | 0.98470 | 0.98470 | 0.98470 |
| M/ EH | 0.98810 | 0.98810 | 0.98810 | 0.98810 | 0.98810 |
| KK DF | 0.06200 | 0.06200 | 0.06200 | 0.06200 | 0.06200 |
| KK DH | 0.06200 | 0.06200 | 0.06200 | 0.06200 | 0.06200 |
| KK EF | 0.21570 | 0.21570 | 0.21540 | 0.21610 | 0.21670 |
| KK EH | 0.21300 | 0.21300 | 0.21280 | 0.21340 | 0.21400 |

PROBABILITY of KILL Data Set: 654

| Range(m)--> | 500 | 1313 | 2125 | 2938 | 3750 |
|---|---|---|---|---|---|
| Posture: | | | | | |
| MOBDF | 0.20570 | 0.22290 | 0.21100 | 0.19670 | 0.20790 |
| MOBDH | 0.20590 | 0.22290 | 0.20950 | 0.19870 | 0.21090 |
| MOBEF | 0.09520 | 0.07480 | 0.03660 | 0.00830 | 0.00130 |
| MOBEH | 0.11980 | 0.09780 | 0.05830 | 0.00880 | 0.00210 |
| FRPDF | 0.40580 | 0.42010 | 0.42150 | 0.44040 | 0.44620 |
| FRPDH | 0.40800 | 0.42000 | 0.42400 | 0.44810 | 0.48380 |
| FRPEF | 0.06100 | 0.05280 | 0.03970 | 0.02430 | 0.01790 |
| FRPEH | 0.05960 | 0.05430 | 0.04000 | 0.02520 | 0.01890 |
| M/ DF | 0.40580 | 0.42010 | 0.42150 | 0.44040 | 0.44620 |
| M/ DH | 0.40800 | 0.42000 | 0.42400 | 0.44810 | 0.48380 |
| M/ EF | 0.11810 | 0.09770 | 0.06100 | 0.02880 | 0.01820 |
| M/ EH | 0.14550 | 0.12310 | 0.08330 | 0.02920 | 0.01920 |
| KK DF | | | | | |
| KK DH | | | | | |
| KK EF | 0.02570 | 0.02060 | 0.01020 | 0.00320 | 0.00040 |
| KK EH | 0.01960 | 0.01440 | 0.00870 | 0.00420 | 0.00130 |

# APPENDIX C. EXAMPLE POSTPROCESSOR FILE

This appendix shows relevant parts of the postprocessor files produced by Janus. The file includes the Coroner's Report and the Engagement Range Analysis. A similar report is generated for each run of each scenario. The Coroner's Report shows the victim and killer type and location, weapon and range for each shot which results in a kill. The Engagement Range Analysis shows the average kill range in addition to the information provided by the Coroner's Report.

CORONER'S REPORT

Run 50 - 59 of Scenario Number 228

SIDE: 1 RUN NUMBER: 50

| | GAME | KILL | | VICTIM | | | | | | | KILLER | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PRJ/WPN/MF | TIME CAUS/RC | Mec/Cat | | UNIT/SIDE | | NAME | X | Y | Loss | UNIT/SIDE | | NAME | X | Y | RANGE |
| AT-11 | 00:00:11:10 | DF | K | 5 | 1 | Sys 92 | 41.3 | 98.4 | 1 | 5 | 2 | T72 | 44.4 | 100.3 | 3.63 |
| AT-11 | 00:00:11:10 | DF | K | 6 | 1 | Sys 92 | 41.8 | 97.9 | 1 | 1 | 2 | T72 | 44.8 | 100.3 | 3.84 |
| AT-5 | 00:00:12:13 | DF | K | 10 | 1 | Sys 92 | 40.6 | 99.0 | 1 | 32 | 2 | BMP-2 | 43.8 | 100.5 | 3.52 |
| AT-11 | 00:00:12:15 | DF | K | 8 | 1 | Sys 92 | 41.1 | 98.6 | 1 | 5 | 2 | T72 | 44.1 | 100.2 | 3.45 |
| AT-11 | 00:00:14:03 | DF | K | 7 | 1 | Sys 92 | 41.5 | 98.2 | 1 | 6 | 2 | T72 | 44.2 | 100.0 | 3.27 |
| AT-11 | 00:00:17:20 | DF | K | 9 | 1 | Sys 92 | 40.0 | 98.7 | 1 | 9 | 2 | T72 | 41.7 | 101.2 | 3.00 |
| AT-11 | 00:00:17:55 | DF | K | 1 | 1 | Sys 92 | 40.2 | 99.3 | 1 | 6 | 2 | T72 | 42.8 | 99.8 | 2.61 |
| AT-5 | 00:00:18:13 | DF | K | 12 | 1 | Sys 92 | 39.7 | 99.0 | 1 | 16 | 2 | BMP-2 | 42.9 | 99.8 | 3.35 |
| AT-5 | 00:00:21:32 | DF | K | 4 | 1 | Sys 92 | 39.7 | 99.3 | 1 | 16 | 2 | BMP-2 | 41.9 | 99.8 | 2.29 |
| AT-11 | 00:00:22:31 | DF | K | 2 | 1 | Sys 92 | 39.3 | 99.5 | 1 | 3 | 2 | T72 | 41.1 | 101.2 | 2.56 |
| 125APFSDS | 00:00:28:47 | DF | K | 3 | 1 | Sys 92 | 38.8 | 99.3 | 1 | 8 | 2 | T72 | 39.2 | 99.6 | .47 |
| 125APFSDS | 00:00:30:16 | DF | K | 11 | 1 | Sys 92 | 38.3 | 99.3 | 1 | 6 | 2 | T72 | 38.0 | 99.6 | .46 |

CORONER'S REPORT

Run 50 - 59 of Scenario Number 228

SIDE: 2 RUN NUMBER: 50

| PRJ/WPN/MF | GAME TIME CAUS/RC | KILL Mec/Cat | | VICTIM UNIT/SIDE | | NAME | X | Y | Loss | KILLER UNIT/SIDE | | NAME | X | Y | RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOW | 00:00:13:43 | DF | K | 31 | 2 | BMP-2 | 42.8 | 100.6 | 1 | 1 | 1 | Sys 92 | 40.2 | 99.3 | 2.88 |
| TOW | 00:00:14:36 | DF | K | 15 | 2 | BMP-2 | 42.5 | 100.9 | 1 | 1 | 1 | Sys 92 | 40.2 | 99.3 | 2.83 |
| TOW | 00:00:16:13 | DF | K | 5 | 2 | T72 | 42.6 | 100.0 | 1 | 9 | 1 | Sys 92 | 40.0 | 98.7 | 2.87 |
| TOW | 00:00:16:47 | DF | K | 1 | 2 | T72 | 42.6 | 99.9 | 1 | 9 | 1 | Sys 92 | 40.0 | 98.7 | 2.88 |
| TOW | 00:00:16:58 | DF | K | 14 | 2 | BMP-2 | 42.5 | 100.5 | 1 | 1 | 1 | Sys 92 | 40.2 | 99.3 | 2.54 |
| TOW | 00:00:17:10 | DF | K | 32 | 2 | BMP-2 | 42.5 | 100.2 | 1 | 9 | 1 | Sys 92 | 40.0 | 98.7 | 2.87 |
| TOW | 00:00:18:08 | DF | K | 9 | 2 | T72 | 41.4 | 101.2 | 1 | 4 | 1 | Sys 92 | 39.7 | 99.3 | 2.56 |
| TOW | 00:00:18:31 | DF | K | 7 | 2 | T72 | 42.3 | 100.5 | 1 | 4 | 1 | Sys 92 | 39.7 | 99.3 | 2.86 |
| TOW | 00:00:18:51 | DF | K | 2 | 2 | T72 | 41.4 | 101.0 | 1 | 2 | 1 | Sys 92 | 39.3 | 99.5 | 2.62 |
| TOW | 00:00:19:59 | DF | K | 10 | 2 | T72 | 41.0 | 101.1 | 1 | 4 | 1 | Sys 92 | 39.7 | 99.3 | 2.25 |
| TOW | 00:00:21:23 | DF | K | 33 | 2 | BMP-2 | 41.0 | 101.2 | 1 | 2 | 1 | Sys 92 | 39.3 | 99.5 | 2.47 |
| TOW | 00:00:22:05 | DF | K | 4 | 2 | T72 | 40.9 | 101.4 | 1 | 2 | 1 | Sys 92 | 39.3 | 99.5 | 2.52 |
| TOW | 00:00:23:32 | DF | K | 3 | 2 | T72 | 40.8 | 101.2 | 1 | 3 | 1 | Sys 92 | 38.8 | 99.3 | 2.69 |

ENGAGEMENT RANGE ANALYSIS

Run 50 - 59 of Scenario Number 228

**** SIDE 1 system Sys 92 killing SIDE 2 system T72 ****

RUN NUMBER 50

| GAME TIME | KILL TYPE | VICTIM UNIT | SIDE | NAME | LOSS | KILLER UNIT | SIDE | NAME | RANGE | PRJ/WPN/MF |
|---|---|---|---|---|---|---|---|---|---|---|
| 00:00:16:13 | DF | 5 | 2 | T72 | 1 | 9 | 1 | Sys 92 | 2.868 | TOW |
| 00:00:16:47 | DF | 1 | 2 | T72 | 1 | 9 | 1 | Sys 92 | 2.876 | TOW |
| 00:00:18:08 | DF | 9 | 2 | T72 | 1 | 4 | 1 | Sys 92 | 2.561 | TOW |
| 00:00:18:31 | DF | 7 | 2 | T72 | 1 | 4 | 1 | Sys 92 | 2.856 | TOW |
| 00:00:18:51 | DF | 2 | 2 | T72 | 1 | 2 | 1 | Sys 92 | 2.619 | TOW |
| 00:00:19:59 | DF | 10 | 2 | T72 | 1 | 4 | 1 | Sys 92 | 2.247 | TOW |
| 00:00:22:05 | DF | 4 | 2 | T72 | 1 | 2 | 1 | Sys 92 | 2.521 | TOW |
| 00:00:23:32 | DF | 3 | 2 | T72 | 1 | 3 | 1 | Sys 92 | 2.691 | TOW |

Total number of kills = 8 Average Range = 2.655

ENGAGEMENT RANGE ANALYSIS

Run 50 - 59 of Scenario Number 228

**** SIDE 1 system Sys 92 killing SIDE 2 system BMP-2 ****

RUN NUMBER 50

| GAME TIME | KILL TYPE | VICTIM UNIT | SIDE | NAME | LOSS | KILLER UNIT | SIDE | NAME | RANGE | PRJ/WPN/MF |
|---|---|---|---|---|---|---|---|---|---|---|
| 00:00:13:43 | DF | 31 | 2 | BMP-2 | 1 | 1 | 1 | Sys 92 | 2.878 | TOW |
| 00:00:14:36 | DF | 15 | 2 | BMP-2 | 1 | 1 | 1 | Sys 92 | 2.834 | TOW |
| 00:00:16:58 | DF | 14 | 2 | BMP-2 | 1 | 1 | 1 | Sys 92 | 2.540 | TOW |
| 00:00:17:10 | DF | 32 | 2 | BMP-2 | 1 | 9 | 1 | Sys 92 | 2.867 | TOW |
| 00:00:21:23 | DF | 33 | 2 | BMP-2 | 1 | 2 | 1 | Sys 92 | 2.469 | TOW |

Total number of kills = 5 Average Range = 2.718

# APPENDIX D.  RAW DATA

This appendix shows the raw data that were used in the analysis. These data were drawn from the Coroner's Reports and the Engagement Range Analysis Reports contained in the postprocessor files from each run conducted.

| Scenario 228 - TOW 2B Desert Terrain | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| | Red T-72 | Red BMP-2 | Blue HMMWV | Red T-72 | Red BMP-2 |
| Run # | Losses | Losses | Losses | Kill Range | Kill Range |
| 50 | 8 | 5 | 12 | 2.655 | 2.718 |
| 51 | 5 | 3 | 12 | 2.747 | 2.872 |
| 52 | 6 | 5 | 12 | 2.654 | 2.602 |
| 53 | 4 | 1 | 12 | 2.441 | 2.878 |
| 54 | 4 | 1 | 12 | 2.441 | 2.878 |
| 55 | 9 | 5 | 12 | 2.782 | 2.774 |
| 56 | 9 | 6 | 12 | 2.705 | 2.437 |
| 57 | 8 | 5 | 12 | 2.655 | 2.718 |
| 58 | 5 | 5 | 12 | 2.716 | 2.837 |
| 59 | 3 | 4 | 12 | 2.819 | 2.784 |
| 60 | 9 | 5 | 12 | 2.700 | 2.727 |
| 61 | 7 | 5 | 12 | 2.665 | 2.811 |
| 62 | 7 | 4 | 12 | 2.706 | 2.729 |
| 63 | 5 | 4 | 12 | 2.764 | 2.570 |
| 64 | 5 | 4 | 12 | 2.764 | 2.570 |
| 65 | 5 | 4 | 12 | 2.764 | 2.570 |
| 66 | 4 | 5 | 12 | 2.597 | 2.728 |
| 67 | 6 | 5 | 12 | 2.654 | 2.602 |
| 68 | 4 | 1 | 12 | 2.441 | 2.878 |
| 69 | 1 | 2 | 12 | 2.416 | 2.689 |
| 70 | 8 | 5 | 12 | 2.310 | 2.683 |
| 71 | 7 | 5 | 12 | 2.713 | 2.741 |
| 72 | 9 | 2 | 12 | 2.687 | 2.946 |
| 73 | 9 | 5 | 12 | 2.700 | 2.727 |
| 74 | 9 | 6 | 12 | 2.716 | 2.841 |

| Scenario 229 - TOW 2B European Terrain | | | | | |
|---|---|---|---|---|---|
| | Red T-72 | Red BMP-2 | Blue HMMWV | Red T-72 | Red BMP-2 |
| Run # | Losses | Losses | Losses | Kill Range | Kill Range |
| 50 | 10 | 4 | 12 | 1.629 | 1.868 |
| 51 | 9 | 4 | 12 | 1.697 | 1.096 |
| 52 | 9 | 6 | 12 | 1.772 | 1.361 |
| 53 | 15 | 6 | 12 | 1.734 | 1.294 |
| 54 | 9 | 5 | 11 | 1.471 | 1.095 |
| 55 | 9 | 5 | 11 | 1.471 | 1.095 |
| 56 | 14 | 5 | 12 | 1.682 | 1.943 |
| 57 | 9 | 4 | 12 | 0.969 | 0.998 |
| 58 | 9 | 5 | 12 | 1.341 | 1.422 |
| 59 | 14 | 5 | 12 | 1.682 | 1.943 |
| 60 | 9 | 5 | 12 | 1.341 | 1.422 |
| 61 | 8 | 4 | 12 | 0.937 | 0.889 |
| 62 | 10 | 4 | 11 | 1.341 | 1.649 |
| 63 | 8 | 2 | 11 | 1.155 | 2.242 |
| 64 | 11 | 5 | 12 | 1.456 | 1.258 |
| 65 | 10 | 4 | 12 | 1.808 | 1.515 |
| 66 | 12 | 5 | 12 | 1.383 | 1.504 |
| 67 | 9 | 4 | 11 | 1.718 | 1.480 |
| 68 | 8 | 4 | 12 | 0.937 | 0.889 |
| 69 | 7 | 4 | 12 | 1.225 | 1.697 |
| 70 | 9 | 6 | 12 | 1.772 | 1.361 |
| 71 | 3 | 3 | 12 | 1.374 | 1.806 |
| 72 | 13 | 7 | 11 | 1.522 | 1.343 |
| 73 | 9 | 5 | 11 | 1.326 | 1.328 |
| 74 | 17 | 8 | 11 | 1.749 | 1.357 |

| Scenario 230 - TOW 2B Mediterranean Terrain | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| | Red T-72 | Red BMP-2 | Blue HMMWV | Red T-72 | Red BMP-2 |
| Run # | Losses | Losses | Losses | Kill Range | Kill Range |
| 50 | 10 | 8 | 12 | 2.731 | 2.726 |
| 51 | 9 | 9 | 12 | 2.778 | 2.800 |
| 52 | 7 | 8 | 12 | 2.744 | 2.820 |
| 53 | 12 | 11 | 12 | 2.826 | 2.661 |
| 54 | 14 | 10 | 12 | 2.679 | 2.879 |
| 55 | 8 | 10 | 12 | 2.651 | 2.796 |
| 56 | 8 | 9 | 12 | 2.624 | 2.814 |
| 57 | 10 | 8 | 12 | 2.731 | 2.726 |
| 58 | 12 | 11 | 12 | 2.826 | 2.661 |
| 59 | 11 | 8 | 12 | 2.748 | 2.806 |
| 60 | 12 | 7 | 12 | 2.750 | 2.831 |
| 61 | 12 | 11 | 12 | 2.826 | 2.661 |
| 62 | 10 | 8 | 12 | 2.731 | 2.726 |
| 63 | 8 | 8 | 12 | 2.680 | 2.815 |
| 64 | 10 | 7 | 12 | 2.623 | 2.752 |
| 65 | 10 | 8 | 12 | 2.704 | 2.742 |
| 66 | 6 | 9 | 12 | 2.440 | 2.870 |
| 67 | 8 | 10 | 12 | 2.651 | 2.796 |
| 68 | 10 | 8 | 12 | 2.704 | 2.742 |
| 69 | 11 | 9 | 12 | 2.661 | 2.779 |
| 70 | 8 | 9 | 12 | 2.624 | 2.814 |
| 71 | 11 | 8 | 12 | 2.740 | 2.806 |
| 72 | 8 | 8 | 12 | 2.779 | 2.716 |
| 73 | 6 | 6 | 12 | 2.724 | 2.503 |
| 74 | 7 | 9 | 12 | 2.702 | 2.692 |

| Scenario 238 - CM Desert Terrain | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| | Red T-72 | Red BMP-2 | Blue HMMWV | Red T-72 | Red BMP-2 |
| Run # | Losses | Losses | Losses | Kill Range | Kill Range |
| 50 | 12 | 7 | 7 | 4.887 | 4.131 |
| 51 | 15 | 18 | 2 | 4.713 | 4.651 |
| 52 | 12 | 8 | 6 | 4.757 | 4.542 |
| 53 | 11 | 8 | 6 | 4.581 | 4.537 |
| 54 | 14 | 8 | 5 | 4.694 | 4.478 |
| 55 | 14 | 9 | 4 | 4.789 | 4.696 |
| 56 | 12 | 18 | 5 | 4.723 | 4.558 |
| 57 | 13 | 9 | 3 | 4.672 | 4.615 |
| 58 | 13 | 9 | 4 | 4.764 | 4.680 |
| 59 | 14 | 9 | 3 | 4.723 | 4.519 |
| 60 | 15 | 9 | 2 | 4.769 | 4.659 |
| 61 | 13 | 9 | 4 | 4.666 | 4.450 |
| 62 | 14 | 8 | 3 | 4.837 | 4.726 |
| 63 | 13 | 8 | 3 | 4.758 | 4.604 |
| 64 | 14 | 9 | 3 | 4.723 | 4.519 |
| 65 | 11 | 7 | 5 | 4.647 | 4.422 |
| 66 | 11 | 7 | 5 | 4.647 | 4.422 |
| 67 | 15 | 8 | 5 | 4.856 | 4.509 |
| 68 | 14 | 8 | 3 | 4.637 | 4.726 |
| 69 | 14 | 8 | 5 | 4.715 | 4.545 |
| 70 | 13 | 9 | 4 | 4.764 | 4.680 |
| 71 | 13 | 8 | 4 | 4.637 | 4.798 |
| 72 | 13 | 8 | 3 | 4.759 | 4.843 |
| 73 | 15 | 8 | 5 | 4.856 | 4.509 |
| 74 | 11 | 8 | 5 | 4.581 | 4.537 |

| Scenario 239 - CM European Terrain | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| | Red T-72 | Red BMP-2 | Blue HMMWV | Red T-72 | Red BMP-2 |
| Run # | Losses | Losses | Losses | Kill Range | Kill Range |
| 50 | 17 | 6 | 12 | 3.016 | 2.883 |
| 51 | 19 | 18 | 12 | 3.252 | 3.117 |
| 52 | 18 | 9 | 12 | 3.381 | 3.655 |
| 53 | 18 | 12 | 8 | 3.413 | 3.379 |
| 54 | 18 | 12 | 8 | 3.413 | 3.379 |
| 55 | 18 | 12 | 8 | 3.150 | 3.125 |
| 56 | 17 | 12 | 9 | 3.262 | 3.014 |
| 57 | 19 | 11 | 9 | 3.248 | 3.140 |
| 58 | 17 | 18 | 11 | 3.285 | 3.306 |
| 59 | 19 | 9 | 10 | 3.309 | 3.249 |
| 60 | 18 | 12 | 8 | 3.124 | 3.029 |
| 61 | 19 | 8 | 12 | 2.911 | 3.035 |
| 62 | 19 | 11 | 8 | 3.012 | 3.022 |
| 63 | 20 | 11 | 8 | 3.255 | 3.187 |
| 64 | 17 | 10 | 11 | 3.285 | 3.306 |
| 65 | 18 | 8 | 12 | 2.967 | 3.193 |
| 66 | 19 | 12 | 10 | 3.069 | 2.955 |
| 67 | 19 | 9 | 12 | 3.243 | 3.243 |
| 68 | 17 | 10 | 11 | 3.285 | 3.306 |
| 69 | 16 | 6 | 12 | 2.936 | 4.206 |
| 70 | 18 | 11 | 10 | 3.424 | 3.104 |
| 71 | 20 | 12 | 6 | 3.095 | 2.914 |
| 72 | 20 | 11 | 8 | 3.001 | 3.203 |
| 73 | 20 | 11 | 8 | 3.255 | 3.187 |
| 74 | 18 | 12 | 8 | 3.124 | 3.029 |

| Scenario 239 - CM European Terrain | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| | Red T-72 | Red BMP-2 | Blue HMMWV | Red T-72 | Red BMP-2 |
| Run # | Losses | Losses | Losses | Kill Range | Kill Range |
| 50 | 20 | 12 | 2 | 4.318 | 4.192 |
| 51 | 20 | 12 | 2 | 4.433 | 4.434 |
| 52 | 20 | 12 | 2 | 4.368 | 4.031 |
| 53 | 28 | 12 | 2 | 4.446 | 3.911 |
| 54 | 20 | 12 | 1 | 4.373 | 4.106 |
| 55 | 20 | 12 | 3 | 4.216 | 3.895 |
| 56 | 20 | 12 | 2 | 4.433 | 4.434 |
| 57 | 20 | 12 | 3 | 4.487 | 3.817 |
| 58 | 20 | 12 | 2 | 4.318 | 4.192 |
| 59 | 20 | 12 | 3 | 4.138 | 4.017 |
| 60 | 20 | 12 | 2 | 4.433 | 4.434 |
| 61 | 20 | 12 | 2 | 4.433 | 4.434 |
| 62 | 18 | 12 | 9 | 4.364 | 4.160 |
| 63 | 20 | 12 | 5 | 4.424 | 3.994 |
| 64 | 20 | 12 | 4 | 4.287 | 3.984 |
| 65 | 20 | 12 | 3 | 4.138 | 4.017 |
| 66 | 18 | 12 | 9 | 4.364 | 4.160 |
| 67 | 20 | 12 | 4 | 4.314 | 4.108 |
| 68 | 20 | 12 | 2 | 4.318 | 4.192 |
| 69 | 19 | 12 | 6 | 4.276 | 4.147 |
| 70 | 20 | 12 | 3 | 4.402 | 4.003 |
| 71 | 19 | 12 | 6 | 4.387 | 4.152 |
| 72 | 20 | 12 | 6 | 4.350 | 3.816 |
| 73 | 18 | 12 | 4 | 4.457 | 4.293 |
| 74 | 20 | 12 | 2 | 4.459 | 4.116 |

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